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TITLE: VIRUS COAT PROTEIN/RECEPTOR CHIMERAS AND  
METHODS OF USE

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## VIRUS COAT PROTEIN/RECEPTOR CHIMERAS AND METHODS OF USE

*Ins. 1/7*  
**STATEMENT AS TO FEDERALLY SPONSORED RESEARCH**

This invention was made with Government support under R01HL59796 awarded by  
5 National Institutes of Health. The Government may have certain rights in the invention.

**FIELD OF THE INVENTION**

This invention relates generally to receptor ligand interactions and more specifically  
to chimeric polypeptides having virus coat polypeptide and cell receptor polypeptide  
10 sequences that bind to each other and mimic the structural, functional and immunogenic  
properties that naturally occur when the virus protein and receptor interact *in vivo*.

**BACKGROUND OF THE INVENTION**

Humoral immunity arising after primary infection with HIV-1 may not prevent  
15 progression to AIDS (R. A. Koup *et al.*, *Nature*, **370**:416 (1994); R. A. Koup *et al.*, *J. Virol.*,  
**68**:4650-5 (1994)). However, it is likely that humoral immunity can prevent infection if an  
individual has high-titered neutralizing antibodies prior to exposure to the virus. This  
concept is largely supported by passive immunization studies in which chimps were  
transfused with neutralizing anti-V3 monoclonal antibodies or pooled, high-titered  
20 neutralizing antisera around the time of challenge with cell-free virus (E. A. Emini *et al.*,  
*Nature*, **355**:728-30 (1992); R. Shibata *et al.*, *Nat. Med.*, **5**:204-10 (1999)). Protection was  
obtained in both sets of studies, indicating that humoral immunity can be protective provided  
the right antibodies are present in sufficient titers at the time of challenge or shortly  
thereafter.

25 Additional studies suggest that humoral immunity can be protective against HIV-1.  
For example, passive immunization using the SCID-hu mouse system have shown that  
human monoclonal antibodies specific for the CD4 binding domain of gp120 can prevent  
infection (M. C. Gauduin *et al.*, *Nat. Med.*, **3**:1389-93 (1997); P.W. Parren *et al.*, *AIDS*, **9**:F1-  
6 (1995)). Second, passive transfer of a bivalent CD4-Ig "immunoadhesin," a chimera made  
30 between CD4 and the human IgG2 heavy chain, can protect in the HIV-1 chimp challenge  
system (J.W. Eichberg *et al.*, *AIDS Res. Hum. Retroviruses*, **8**:1515-9 (1992); R.H. Ward

*et al.*, *Nature*, **352**:434-6 (1991)). Third, neutralizing antibodies correlate strongly with protective immunity against SIV (J.L. Heeney *et al.*, *Proc. Natl. Acad. Sci. U.S.A.*, **95**:10803-8 (1998)). Fourth, passive transfer studies in rhesus macaques showed that high-titered chimp antibodies specific for the HIV-1<sub>DH12</sub> isolate provide sterilizing immunity in rhesus macaques against SHIV<sub>DH12</sub> if a sufficient concentration of the antibodies was used (R. Shibata *et al.*, *Nat. Med.*, **5**:204-10 (1999)). Fifth, passive-transfer experiments in rhesus macaques using HIVIg, 2G12, and 2F5 demonstrated 50% better protection in recipient groups compared to non-recipient controls against challenge with SHIV-89.6P (Mascola *et al.*, *J. Virol.*, **73**:4009-18 (1999)).

These studies support the idea that immunization strategies which elicit persistent, high-titered (or highly effective) neutralizing antibody responses of broad specificity may be protective. A successful strategy to reach this goal has been elusive. The subunit formulations of recombinant monomeric or oligomeric HIV envelope that have been tested elicit neutralizing responses against a narrow range of isolates (J.P. Moore *et al.*, *AIDS*, **9**:S117-136 (1995); Q. J. Sattentau, *Curr. Opin. Immunol.*, **8**:540-5 (1996); R. Wyatt *et al.*, *Science*, **280**:1884-8 (1998)).

### SUMMARY OF THE INVENTION

In accordance with the present invention, there are provided chimeric polypeptides containing a virus coat polypeptide sequence and a viral receptor polypeptide sequence in which the coat polypeptide sequence and the receptor polypeptide sequence are linked by a spacer. The coat polypeptide and the viral receptor polypeptide sequences of the chimeric polypeptides can bind to each other. Invention chimeric polypeptides are useful for inducing an immune response and for producing antibodies. Invention chimeric polypeptides also are useful for preventing, inhibiting, or ameliorating a viral infection by passive protection against virus infection or by production of an immune response (*i.e.*, antibodies or a CTL response) by administration to a subject, for example.

In various embodiments, the virus coat polypeptide sequence of a chimeric polypeptide is an envelope polypeptide sequence (*e.g.*, full-length gp120 or a fragment), a virus that binds a co-receptor polypeptide, an immunodeficiency virus, including HIV (*e.g.*, HIV-1 or HIV-2), SIV, FIV, FeLV, FPV, and a herpes virus. In various additional

embodiments, the viral receptor polypeptide sequence is a CD4 polypeptide sequence, *full-length* or a fragment thereof, such as the D1 and D2 domains. Introducing envelope genes derived from viruses that use alternative co-receptors could further expand the potential of these single chain molecules affording protection from viral infection of different cell types that express the different co-receptors.

Chimeric polypeptides having heterologous domains also are provided. Such heterologous domains impart a distinct functionality and include tags, adhesins and immunopotentiating agents, for example. Heterologous domains can have an amino acid sequence, such as a c-myc polypeptide sequence or an immunoglobulin polypeptide sequence (*e.g.*, a heavy chain polypeptide sequence).

In accordance with the present invention, there are provided polynucleotide sequences having a nucleic acid sequence encoding invention chimeric polypeptides. The polynucleotides can be included in an expression vector and are useful for expressing chimeric polypeptides.

In accordance with the present invention, there are provided antibodies and functional fragments thereof that bind to the invention chimeric polypeptides. The antibodies are useful in treatment methods and in diagnostic methods. Such antibodies can neutralize the immunodeficiency virus *in vitro* or *in vivo*, and can also be useful in inhibiting immunodeficiency virus infection, for example, by passive protection. Such antibodies can bind to an epitope produced by the binding of the virus coat polypeptide sequence and viral receptor polypeptide sequence. Such an epitope can be present on an envelope polypeptide sequence, for example.

The chimeric polypeptides, polynucleotides and antibodies of the invention are useful for treating viral infection, or for inducing an immune response, for example. Thus, in accordance with the present invention, there are provided chimeric polypeptides, polynucleotides and antibodies in a pharmaceutically acceptable carrier.

Methods for producing an antibody include administering an invention chimeric polypeptide in an amount sufficient for the subject to produce antibodies to the chimeric polypeptide. Such methods also can be useful, for example, for inhibiting or ameliorating virus infection in a subject, or for passive protection, when the antibody is administered to a recipient subject.

Methods for inhibiting virus infection in a subject include administering an effective amount of an invention chimeric polypeptide, or a polynucleotide encoding an invention chimeric polypeptide, to inhibit virus infection of a cell. The administered chimeric polypeptide can prevent virus infection by binding to a viral co-receptor on the cells of the subject or produce a protective immune response. The chimeric polypeptide can be administered in an amount sufficient to ameliorate the virus infection in the subject. A method that produces an immune response can produce an antibody response or a CTL response. The antibodies produced can neutralize the immunodeficiency virus *in vitro*. The antibodies also may bind to an epitope exposed by the binding of the two polypeptide sequences of the chimeric polypeptide.

Methods for identifying agents that modulate binding or interaction between a virus and a virus co-receptor, and a virus and a virus receptor, also are provided. In one embodiment, a method includes contacting a chimeric polypeptide having a coat protein of a virus that binds to a co-receptor with a co-receptor polypeptide (*e.g.*, a CCR5 or CXCR4 polypeptide sequence) under conditions allowing the chimeric polypeptide and the co-receptor polypeptide to bind, in the presence and absence of a test agent, and detecting binding in the presence and absence of the test agent. Decreased binding in the presence of the test agent identifies an agent that inhibits binding between the virus and the virus co-receptor polypeptide. In another embodiment, a method includes contacting a chimeric polypeptide under conditions allowing intramolecular binding within the chimeric polypeptide, in the presence and absence of a test agent, and detecting intramolecular binding or interaction within the chimeric polypeptide. Decreased binding in the presence of the test agent identifies an agent that inhibits intramolecular binding or interaction between the virus and the virus receptor polypeptide in the chimera.

The agent can be added before or after contacting the chimeric polypeptide with the virus co-receptor polypeptide. The virus co-receptor or receptor polypeptide can be present on the surface of an intact cell, which can be present in an animal, such as a non-human primate. The methods can be performed using an immunodeficiency virus, such as HIV, SIV, and the like. Test agents include a library of agents, such as peptides, organic molecules, antibodies and fragments thereof, antivirals, virus co-receptors, functional fragments, and peptide mimetics thereof.

Methods for identifying a chimeric polypeptide sequence that modulate (inhibits or stimulates) virus infection of a cell also are provided. In one embodiment, a method includes contacting a cell susceptible to virus infection with an infectious virus particle in the presence and absence of the chimeric polypeptide sequence; and determining whether the chimeric polypeptide modulates (inhibits or stimulates) virus infection of the cell (*in vitro* or *in vivo*).

### **BRIEF DESCRIPTION OF THE DRAWINGS**

**FIG. 1** is a diagram of a polynucleotide construct that encodes exemplary chimeric polypeptides. Full-length single chain (FLSC) chimeric polypeptide comprises an HIVgp120 (BaL strain), a 20 amino acid spacer polypeptide, a CD4 polypeptide sequence comprising the D1 and D2 domains (D1D2), and a myc peptide "tag." Truncated single chain (TcSC) chimera contains deletions in the C1 (constant region 1), V1 (variable region 1), V2, and C5. FLSC R/T chimera has a single mutation in the furin cleavage site, an R is changed to a T, at the c-terminus of gp120. The deletions indicated for TcSC are numbered according to the BaL gp120 sequence.

**FIG. 2** is a Western blot analysis of cell culture supernatant containing FLSC and TcSC soluble chimeric polypeptide expressed by 293-SC cells. Immunoblotting was performed with gp120 (lanes 1 to 4) and CD4 (lanes 5 to 8) and the arrows indicate, in order of decreasing gel mobility, gp120-CD4 single chain (single chain), cleaved gp120 (gp120 fragment) and cleaved CD4 (CD4 fragment).

**FIG. 3** is an analysis of gp120-CD4 expressed by 293-SC cells; uncrosslinked gp120-CD4 is in lane 1 and the crosslinked gp120-CD4 is in lane 2.

**FIG. 4** is an immunoblot analysis of FLSC after crosslinking. The relative percent (%) total protein for each of the different FLSC concentrations (1-0.03  $\mu$ M) are shown in the bar graph: (A), 65% 172kD; (B), 25% 302kD; and (C), 10% higher order oligomer.

**FIG. 5A-5C** is a binding analysis of gp120-CD4 chimera. (A), Full length single chain (FLSC) incubated with anti-gp120 antibodies (17b, 48d, A32 and C11) in comparison to crosslinked gp120/rsCD4 and uncomplexed gp120. 17b, 48d and A32 have preferential affinity for complexed gp120 (gp120). Bars are shown with standard error. (B), Reciprocal half-maximal binding concentration of human anti-gp120 monoclonal antibodies in FLSC

and TcSC (ELISA). (C), Reciprocal half-maximal binding of monoclonal antibodies IgG1b12, F91 and 205-469, which react with the gp120 CD4 binding domain.

**FIG. 6** is an analysis of gp120-CD4 chimera (FLSC, TcSC) binding to CCR5 (R5) or CXCR4 (X4) co-receptor expressing L1.2 cells. Control cells that do not express CCR5 or CXCR4 are denoted L1.2. Bound complexes were detected by flow cytometry using 5 µg/ml of anti-CD4 Mab45. The values shown are of a representative study performed three times.

**FIG. 7** is an analysis of gp120-CD4 (FLSC, TcSC) binding to co-receptor in the presence of gp120 binding antibodies (17b, 48d, A32, C11 and 2G12), and a gp41 antibody (F240). L1.2 cells expressed co-receptor CCR5 (R5), CXCR4 (X4), or no co-receptor (L1.2), as indicated. Antibody-free controls are denoted "+." Background measurements obtained with untreated cells are denoted "-." Bound complexes were detected by flow cytometry using 5 µg/ml Mab45. Results are presented as percent binding relative to the mean fluorescence intensity obtained in the matched control assay. Average values derived from three separate studies are shown. Standard errors are shown with bars.

**FIG. 8** is an analysis of HIV-1<sub>2044</sub> (an X4-specific isolate) and HIV-1<sub>BaL</sub> (an R5-specific isolate) virus neutralization by FLSC, TcSC BaLgp120 and BaLgp120-rsCD4 complexes. U373 cells expressed CD4, either R5 or X4, and β-galactosidase regulated by the HIV-1LTR promoter. An ID<sub>90</sub> for FLSC and TcSC against HIV-1<sub>2044</sub> was not achieved with the maximum concentrations tested and is therefore presented as >10 µg/ml.

**FIG. 9** is a diagram of chimeric gp120-CD4-IgG1 gene showing the coding domains. It is essentially the original gp120-CD4 subcloned into a plasmid that has the IgG1 heavy chain C1, C2 and C3 regions thereby permitting expression of chimeric gp120-CD4-IgG1 polypeptide.

**FIG. 10** is an immunoblot analysis of a gp120-CD4-IgG1 chimeric polypeptide expressed in 293 cells. The chimeric gp120-CD4-IgG1 was isolated from culture supernatant (lane 1) and is shown in comparison to purified HIV strain BaL gp120 polypeptide (lane 2). Cleaved gp120 is indicated by the arrow and co-migrates with purified gp120.

**FIG. 11** is a reciprocal dilution analysis of gp120-CD4-IgG1 chimeric polypeptide binding to co-receptor expressing L1.2 cells. CCR5 and CXCR4 expressing L1.2 cells are as indicated.

**FIG. 12** is an analysis of a blocking mAb (17b) on FLSC-IgG1 binding to CCR5 expressing cells showing that FLSC-IgG1 interacts with the R5 co-receptor via the R5-binding domain on gp120.

**FIG. 13** shows the improved stability of gp120-CD4 (FLSC) molecules following mutation of furin cleavage site (R->T).

### **DETAILED DESCRIPTION OF THE INVENTION**

The present invention is based on the discovery that a chimeric polypeptide comprising an HIV envelope polypeptide and a CD4 receptor can form an interacting complex capable of binding to a co-receptor. In the chimeric polypeptide, HIV gp120 binding to CD4 mimics the envelope protein-CD4 transition state that occurs when HIV binds CD4 present on cells; gp120 displays conserved epitopes exposed upon complex formation that interact directly with co-receptor, CCR5. Formation of the envelope-CD4 transition state and subsequent binding to cell co-receptor is a critical step in HIV infection of cells. Therefore, antibodies or other agents that prevent or inhibit gp120-CD4 binding to co-receptor, for example, by binding epitopes exposed upon gp120-CD4 complex formation could inhibit virus interaction with co-receptor thereby mediating protection from HIV infection.

Accordingly, invention chimeric polypeptides or a nucleic acids encoding chimeric polypeptides can be used therapeutically for treating, inhibiting, preventing or ameliorating virus infection, for example, by inducing an immune response to the transition state complex formed upon binding of a virus coat protein to a receptor polypeptide. Such chimeric polypeptides, also referred to herein as "single chain" molecules, can be used to screen for agents that inhibit, prevent or disrupt the binding of the coat polypeptide sequence to the polypeptide receptor sequence within the chimeric sequence, or binding of the chimera to a co-receptor polypeptide sequence, thereby identifying potential therapeutics for treating the corresponding viral infection. For example, an agent that inhibits, prevents or disrupts immunodeficiency virus envelope polypeptide-CD4 complex binding to CCR5 can be a therapeutic agent for treating a subject having or at risk of having HIV.

Chimeric polypeptides are also useful for producing antibodies specific for the interacting coat protein-receptor complex. Such specific antibodies can be used for passive



protection against virus infection or proliferation, for diagnostic purposes and for identifying and characterizing epitopes exposed upon complex formation (e.g., a cryptic epitope). Even in the absence of intramolecular binding between virus coat protein and receptor, a chimeric polypeptide may be more effective at eliciting an immune response than a virus coat polypeptide sequence alone. Accordingly, such non-interacting chimeric polypeptides also are valuable and are included herein.

Chimeric polypeptides containing a virus coat polypeptide that binds a receptor and co-receptor have the additional advantage of passively protecting against virus infection by inhibiting virus access to cell co-receptors *in vivo*. Moreover, such chimeric polypeptides can be used to screen for therapeutics by identifying agents that inhibit, prevent or disrupt the binding of the chimeric polypeptide to co-receptor. For example, an agent that inhibits, prevents or disrupts immunodeficiency virus envelope polypeptide-CD4 complex binding to CCR5 can be a therapeutic agent for treating a subject having or at risk of having HIV. As virus binding to cell receptors is required for virus infection of any cell, chimeric polypeptides comprising a polypeptide sequence of any virus coat protein and a corresponding receptor are included in the invention compositions and methods.

In accordance with the present invention, there are provided chimeric polypeptides comprising a virus coat polypeptide sequence and a viral receptor polypeptide sequence linked by a spacer. The coat polypeptide sequence and receptor polypeptide sequence of the chimeric polypeptide are linked by a spacer, such that the two polypeptide sequences of the chimeric polypeptide preferably bind or interact. In one embodiment, the coat polypeptide sequence is an envelope polypeptide sequence of an immunodeficiency virus. In another embodiment, the coat polypeptide sequence is from a virus that binds a co-receptor polypeptide. In various other embodiments, the coat polypeptide sequence and the receptor polypeptide sequence are active fragments of a corresponding full-length native sequence.

As used herein, the term "coat" means a polypeptide sequence of virus origin that can bind to cells. Generally, virus coat proteins are present near the exterior surface of the virus particle and allow binding and subsequent penetration into the cell membrane. However, a coat polypeptide sequence includes any virus protein capable of binding to or interacting with a receptor polypeptide. Coat polypeptide sequences as defined herein may be non-covalently or covalently associated with other molecular entities, such as carbohydrates, fatty

acids, lipids and the like. Coat polypeptide sequences may contain multiple virus polypeptide sequences. For example, a gag polypeptide sequence may also be included with an envelope polypeptide sequence in a chimeric polypeptide to maintain the envelope polypeptide sequence in a conformation that binds to a receptor polypeptide sequence.

Virus coat polypeptide sequences useful in the invention chimeric polypeptides can be of any origin including, for example, bacterial, plant, and animal viruses, so long as a corresponding cell receptor is known or can be identified. Examples of particular virus included are: *Retroviridae* (e.g human immunodeficiency viruses, such as HIV); *Picornaviridae* (e.g., polio viruses, hepatitis A virus; enteroviruses, human coxsackie viruses, rhinoviruses, echoviruses); *Calciviridae* (e.g., strains that cause gastroenteritis); *Togaviradae* (e.g., equine encephalitis viruses, rubella viruses); *Flaviridae* (e.g., dengue viruses, encephalitis viruses, yellow fever viruses); *Coronaviridae* (e.g., coronaviruses); *Rhabdoriridae* (e.g., vesicular stomatitis viruses, rabies viruses); *Filoviridae* (e.g., ebola viruses); *Paramyxoviridae* (e.g., parainfluenza viruses, mumps virus, measles virus, respiratory syncytial virus); *Orthomyxoviridae* (e.g., influenza viruses); *Bungaviridae* (e.g., Hantaan viruses, bunga viruses, phleboviruses and Nairo viruses); *Arena viridae* (hemorrhagic fever viruses); *Reoviridae* (e.g., reoviruses, orbiviruses and rotaviruses); *Birnaviridae*; *Hepadnaviridae* (Hepatitis B virus); *Parvoviridae* (parvoviruses); *Papovaviridae* (papilloma viruses, polyoma viruses); *Adenoviridae* (most adenoviruses); *Herpesviridae* (herpes simplex virus (HSV) 2 and 2, varicella zoster virus, cytomegalovirus (CMV), herpes viruses); *Poxviridae* (variola viruses, vaccinia viruses, pox viruses); and *Iridoviridae* (e.g., African swine fever virus); and unclassified viruses (e.g., the etiological agents of Spongiform encephalopathies, the agent of delta hepatitis (thought to be a defective satellite of hepatitis B virus), the agents of non-A, non-B hepatitis (class 1 = internally transmitted; class 2 = parenterally transmitted (i.e., Hepatitis C); Norwalk and related viruses, and astroviruses). (See also, Table 1).

As used herein, the term "receptor" means any polypeptide expressed by a cell that a virus can bind. Generally, such receptors are naturally present on the surface of a cell, but can be engineered. Receptor polypeptides may be non-covalently or covalently associated with other molecular entities, such as carbohydrates, fatty acids, lipids and the like. A receptor polypeptide may comprise one or multiple contiguous polypeptide segments that are

covalently or non-covalently attached. Such molecular entities or other polypeptide sequences may be important for receptor conformation, for example, for binding to a coat polypeptide sequence. Thus, additional elements including molecules important for receptor conformation may therefore be included in the invention chimeric polypeptides.

5           The receptor polypeptide sequence can be either prokaryotic or eukaryotic in origin. If eukaryotic, both plant and animal receptors are contemplated. Preferred animal receptors are mammalian, including human and primates, for example, chimps, apes, macaques, gibbons, orangutans and the like, as well as other animal species, including domestic animals and livestock. An example of a human receptor is CD4. Other examples of receptors include  
10       glycosaminoglycan and CD2, CR1. Additional receptors are known and are applicable in the compositions and methods of the invention (see, for example, Table 1; see also "Cellular Receptors For Animal Viruses" Eckard Wimmer, ed; Cold Spring Harbor Press (1994)).

TABLE 1

RECEPTOR (BINDING SUBUNIT)	VIRUS (FAMILY)	REFERENCES
<b>Immunoglobulin-like Molecules</b>		
VCAM-1	EMC-D (Picornaviridae)	Huber (1994)
[CAM-1] (first domain)	Major group HRVs, CAV 13, 18, 21 (picornaviridae)	Colonno <i>et al.</i> (1986); Greve <i>et al.</i> (1989); Staunton <i>et al.</i> (1989); Tomassini <i>et al.</i> (1989)
PVR (first domain)	Polioviruses (Picornaviridae)	Koike <i>et al.</i> (1990); Mendelsohn <i>et al.</i> (1989)
CD4 (first domain)	HIV-2, 2; SIV (Lentiviridae) human herpesvirus 7	Dalgleish <i>et al.</i> (1984); Klatzmann <i>et al.</i> (1984) Lusso <i>et al.</i> (1994)
CEA, several members (first domain)	Mouse hepatitis virus (Coronaviridae)	Williams <i>et al.</i> (1991)
MHC I	Semliki Forest virus? (Togaviridae) Factate dehydrogenase virus Mouse cytomegalovirus (Herpesviridae) SV-40	Helenius <i>et al.</i> (1978); Oldstone <i>et al.</i> (1980); Inada and Mims (1984); Wykes <i>et al.</i> (1993); Breau <i>et al.</i> (1992)
MHC II	Visna virus (Lentiviridae)	Dalziel <i>et al.</i> (1991)
<b>Integrins</b>		
VLA-2 ( $\alpha$ -chain)	ECHO virus 1.8 (Picornaviridae)	Bergelson <i>et al.</i> (1992, 1993)
(RGD-binding protein)	FMDV (Picornaviridae)	Fox <i>et al.</i> (1989); Mason <i>et al.</i> (1994)
$\alpha_v\beta_3$ (vibronectin)	CAV 9, ECHO virus 22 (Picornaviridae)	Roivainen <i>et al.</i> (1994)
<b>Transport Proteins</b>		
Phosphate transporter Analogon	Gibbon ape leukemia virus (Retroviridae) Amphotropic murine Leukemia virus (Retroviridae)	Johann <i>et al.</i> (1992) Miller <i>et al.</i> (1994)
Cationic amino acid transporter	Ecotropic murine leukemia virus (Retroviridae)	Albritton <i>et al.</i> (1989)
<b>Signaling Receptors</b>		
LDL receptor protein family	Minor group HRVs (Picornaviridae) Subgroup A avian leukosis Sarcoma virus (family?)	Hofer <i>et al.</i> (1994) Bates <i>et al.</i> (1993); Connolly <i>et al.</i> (1994)
Acetylcholine receptor ( $\alpha$ -1)	Rabies virus (Rhabdoviridae)	Leniz (1990)
EGF receptor	Vaccinia virus (Poxviridae)	Marsh and Eppstein (1987)
Leukocyte differentiation antigen [CD9]	Feline immunodeficiency virus (Lentiviridae)	Willett <i>et al.</i> (1994)
<b>Others</b>		
Aminopeptidase	Human corona virus 229E (Coronaviridae) TGEV (Coronaviridae)	Yeager <i>et al.</i> (1992) Delmas <i>et al.</i> (1992)
Complement receptor CR2	EBV (Herpesviridae)	McClure (1992)
High affinity laminin receptor	Sindbis virus (Togaviridae)	Wang <i>et al.</i> (1992)

**TABLE 1 (Continued)**

RECEPTOR (BINDING SUBUNIT)	VIRUS (FAMILY)	REFERENCES
Decay-accelerating factor [CD55]	ECHO viruses 7 (6, 11, 12, 20, 21,)	Bergelson <i>et al.</i> (1994)
Membrane cofactor protein	Measles virus (Morbilliviridae)	Dörig <i>et al.</i> (1993)
Moesin	Measles virus (Morbilliviridae)	Dunster <i>et al.</i> (1994)
Glycophorin A	EMCV (Picornaviridae) Reovirus (Reoviridae)	Allaway and Barnes (1986) Paul and Lee (1987)
Galactosylceramide	HIV-1 (Lentiviridae)	Bhat <i>et al.</i> (1991)
Erythrocyte P antigen	Parvovirus B19 (Parvoviridae)	Brown <i>et al.</i> (1993)
BLVRcp. 1	Bovine leukemia virus (Retroviridae)	Ban <i>et al.</i> (1993)
Sialoglycoprotein GP-2	Sendai virus (Paramyxoviridae)	Suzuki <i>et al.</i> (1985)
Sialic acid	Influenza virus (Orthomyxoviridae) Reoviridae (Reoviridae) Group A porcine rotavirus (Rotaviridae) Human coronavirus OC43, bovine coronavirus (Coronaviridae)	Herrler <i>et al.</i> (1985)  Fernandes <i>et al.</i> (1994) Rolsma <i>et al.</i> (1994)  Vlasak <i>et al.</i> (1988)
Heparan sulfate	Human cytomegalovirus (Herpesviridae) HSV	Compton <i>et al.</i> (1993)  WuDunn and Spear (1989)

As used herein, the term "co-receptor" means any receptor that is bound after or in conjunction with virus binding to receptor. Thus, co-receptors include any polypeptide or molecular entity present on a cell that facilitates virus entry, directly or indirectly, by binding to virus polypeptide-receptor complex. In addition to co-receptors that facilitate virus-entry into cells, also included are co-receptors that mediate cell attachment or tropism without directly or indirectly facilitating virus entry. Particular examples of co-receptors are the 7-transmembrane domain (7-TM) containing chemokine receptors, such as CCR5 and CXCR4, which can bind immunodeficiencyvirus. Additional co-receptors include CCR-2b, CCR3, CCR8, V28/CXCR1, US28, STRL 33/BOB/TYMSTR, GPR15/Bonzo and GPR1.

As used herein, the terms "polypeptide," "protein," and "peptide" are used interchangeably to denote a sequence polymer of at least two amino acids covalently linked by an amide bond, regardless of length or post-translational modification (*e.g.*, glycosylation, phosphorylation, lipidation, myristilation, ubiquitination, etc.). D- and L-amino acids, and mixtures of D- and L-amino acids are included. Chimeric polypeptide refers to an amino acid sequence having two or more parts which generally are not found together in an amino acid sequence in nature.

As disclosed herein, a chimeric polypeptide having a CD4 polypeptide sequence and an HIV envelope gp120 polypeptide sequence that binds CD4 can bind to each other in the chimera when separated by an amino acid spacer sequence. The gp120-CD4 chimera is capable of binding co-receptor, such as CCR5. Thus, in another embodiment, the chimeric polypeptide has a coat polypeptide sequence of a virus that binds a co-receptor.

CD4 appears to be the target for entry of a variety of viruses associated with immunodeficiency. For example, cells of the immune system, such as lymphocytes and macrophages express CD4, and are susceptible to infection by HIV, SIV, herpes virus 7 and many other viruses. As used herein, the term "immunodeficiency," when used in reference to a virus, means that the virus is capable of infecting cells of immune origin or cells that participate in immune responsiveness, and generally such infection can compromise an infected host's immune function. Thus, the invention is applicable to any virus coat polypeptide of any virus or virus strain that can bind CD4.

In accordance with the present invention, there are provided chimeric polypeptides having an immunodeficiency virus envelope polypeptide sequence. In various aspects, the

envelope polypeptide sequence is a polypeptide sequence of HIV, HTLV, SIV, FeLV, FPV, and Herpes virus. In other aspects, the virus is a macrophage tropic or a lymphocyte tropic HIV. In another aspect, the HIV is HIV-1 or HIV-2. In various other aspects, the envelope polypeptide sequence is gp120, gp160 or gp41.

5 Receptor and virus coat polypeptide sequences of the chimeric polypeptide require a spacer region between them, for example, for forming an interacting complex between the two polypeptides. Although not wishing to be bound by theory, it is believed that the spacer allows the movement or flexibility between receptor and virus coat polypeptide sequences to form an interacting complex.

10 As used herein, the term "spacer" refers to a physical or chemical moiety, or covalent or non-covalent bond of any size or nature that connects the virus coat polypeptide sequence to the receptor polypeptide sequence while affording the needed flexibility or movement for forming an interacting complex. In the present invention, the spacer preferably links the two polypeptide sequences in an "end to end" orientation. "End to end" means that the amino or  
15 carboxyl terminal amino acid of the coat polypeptide is connected to the amino or carboxyl terminal amino acid of the receptor polypeptide sequence. Thus, a spacer can connect the carboxyl terminal amino acid of the coat polypeptide sequence to the amino terminal amino acid of the receptor polypeptide sequence, as exemplified herein for HIV gp120 and CD4, for example. Alternatively, the spacer can connect the amino terminal amino acid of the coat  
20 polypeptide to the carboxyl terminal amino acid of the receptor polypeptide or the carboxyl terminal amino acids of the polypeptide sequences or the two amino terminal amino acids of the polypeptide sequences.

Particular examples of spacers include one or more amino acids or a peptidomimetic. An amino acid spacer can essentially be any length, for example, as few as 5 or as many as  
25 200 or more amino acids. Thus, an amino acid spacer can have from about 10 to about 100 amino acids, or have from about 15 to about 50 amino acids. Preferably, the spacer has from about 20 to about 40 amino acids. Other examples of spacers include a disulfide linkage between the termini of the polypeptide sequences. A carbohydrate spacer also is contemplated. Those skilled in the art will know or can readily ascertain other moieties that  
30 can function to allow formation of an interacting complex between the virus coat polypeptide sequence and receptor polypeptide sequence.

Receptor and coat polypeptide sequences can be of any amino acid length. Preferably, they have a length that allows the polypeptide sequences to bind to each other when in a chimeric polypeptide. Thus, receptor and coat polypeptide sequences include native full-length receptor and full-length coat polypeptide sequences as well as parts of the polypeptide sequences. For example, amino acid truncations, internal deletions or subunits of receptor, and coat polypeptide sequences are included. Preferably, such modified forms are capable of interacting with each other. For example, it is preferable that a truncated or deleted coat polypeptide sequence is capable of interacting with a receptor polypeptide sequence. An example of a truncated receptor polypeptide sequence is the CD4 D1 and D2 domains, which are capable of interacting with HIV envelope polypeptide sequence (FIG. 9). An example of a truncated coat polypeptide sequence is a truncated HIV gp120 lacking the amino terminal 60 amino acids and carboxy terminal 20 amino acids (e.g., in TcSC).

Thus, in accordance with the present invention, chimeric polypeptides, including truncated or internally deleted sequences, are provided. In one embodiment, the virus coat polypeptide sequence or the receptor polypeptide sequence has one or more amino acids removed in comparison to their corresponding full-length polypeptide sequence. In one aspect, the truncated virus coat polypeptide sequence is an HIV envelope polypeptide sequence and, in another aspect, the truncated receptor polypeptide sequence is a CD4 sequence. As exemplified herein, the truncated HIV envelope polypeptide sequence is a gp120 lacking the amino terminal 60 amino acids or the carboxy terminal 20 amino acids, and a truncated CD4 polypeptide comprising the D1 and D2 domains. In various other aspects, the chimeric polypeptide comprises an internally deleted virus coat polypeptide sequence or an internally deleted CD4 polypeptide sequence.

In addition to the truncated, internally deleted and subunit polypeptide sequences, additional polypeptide sequence modifications are included. Such modifications include minor substitutions, variations, or derivitizations of the amino acid sequence of one or both of the polypeptide sequences that comprise the chimeric polypeptide, so long as the modified chimeric polypeptide has substantially the same activity or function as the unmodified chimeric polypeptide. For example, a virus coat or receptor polypeptide sequence may have carbohydrates, fatty acids (palmitate, myristate), lipids, be phosphorylated or have other post-translational modifications typically associated with polypeptide sequences.



As used herein, the term “substantially the same activity or function,” when used in reference to a chimeric polypeptide so modified, means that the polypeptide retains most, all or more of the activity associated with the unmodified polypeptide, as described herein or known in the art. For example, truncations or internal deletions that do not significantly disrupt (e.g., destroy) the interaction between the virus coat polypeptide sequence and the receptor polypeptide sequence are included herein, as in the exemplified CD4 polypeptide sequence truncation. Similarly, modifications that do not affect the ability of chimeric polypeptide to interact with co-receptor are included herein. Likewise, chimeric polypeptide modifications that do not affect the ability to induce a more potent immune response than administration of the virus coat protein alone are included.

Modified chimeric polypeptides that are “active” or “functional” included herein can be identified through a routine functional assay. For example, by using antibody binding assays, co-receptor binding assays (in solution, *in vitro* in intact cells, e.g, Examples IV, etc.), or determining induction of epitopes exposed in a transition state complex normally hidden when the two polypeptide sequences do not bind, one can readily determine whether the modified chimeric polypeptide has activity. Chimeric polypeptides that induce a more potent immune response can be identified by measuring antibody titers following administration of the chimera to a subject, for example. Modifications that destroy the interaction between the virus coat polypeptide sequence and the receptor polypeptide sequence, or the ability of a chimeric polypeptide having a virus coat polypeptide sequence and receptor sequence which do not interact to induce a more potent immune response, do not have substantially the same activity or function as the corresponding, unmodified chimeric polypeptide and, as such, are not included.

As used herein, the terms “homology” or “homologous,” used in reference to polypeptides, refers to amino acid sequence similarity between two polypeptides. When an amino acid position in both of the polypeptides is occupied by identical amino acids, they are homologous at that position. Thus, by “substantially homologous” means an amino acid sequence that is largely, but not entirely, homologous, and which retains most or all of the activity as the sequence to which it is homologous.

As the modified chimeric polypeptides will retain activity or function associated with unmodified chimeric polypeptide, modified chimeric polypeptides will generally have an

amino acid sequence “substantially identical” or “substantially homologous” with the amino acid sequence of the unmodified polypeptide. As used herein, the term “substantially identical” or “substantially homologous,” when used in reference to a polypeptide sequence, means that a sequence of the polypeptide is at least 50% identical to a reference sequence.

5 Modified polypeptides and substantially identical polypeptides will typically have at least 70%, alternatively 85%, more likely 90%, and most likely 95% homology to a reference polypeptide. For polypeptides, the length of comparison to obtain the above-described percent homologies between sequences will generally be at least 25 amino acids, alternatively at least 50 amino acids, more likely at least 100 amino acids, and most likely  
10 200 amino acids or more.

As set forth herein, substantially identical or homologous polypeptides include additions, truncations, internal deletions or insertions, conservative and non-conservative substitutions, or other modifications located at positions of the amino acid sequence which do not destroy the function of the chimeric polypeptide (as determined by functional assays, *e.g.*, as described herein). A particular example of a substitution is where one or more amino  
15 acids is replaced by another, chemically or biologically similar residue. As used herein, the term “conservative substitution” refers to a substitution of one residue with a chemically or biologically similar residue. Examples of conservative substitutions include the replacement of a hydrophobic residue, such as isoleucine, valine, leucine, or methionine for another, the replacement of a polar residue for another, such as the substitution of arginine for lysine,  
20 glutamic for aspartic acids, or glutamine for asparagine, and the like. Those of skill in the art will recognize the numerous amino acids that can be modified or substituted with other chemically similar residues without substantially altering activity.

Substantially identical or homologous polypeptides also include those having  
25 modifications that improve or confer an additional function or activity. For example, FLSC R/T has a mutated furin site which increases stability of the modified FLSC (see, *e.g.*, FIG. 13).

Modified polypeptides further include “chemical derivatives,” in which one or more of the amino acids therein have a side chain chemically altered or derivatized. Such  
30 derivatized polypeptides include, for example, amino acids in which free amino groups form amine hydrochlorides, p-toluene sulfonyl groups, carbenzoxymethyl groups; the free carboxy

groups form salts, methyl and ethyl esters; free hydroxyl groups that form O-acyl or O-alkyl derivatives, as well as naturally occurring amino acid derivatives, for example, 4-hydroxyproline, for proline, 5-hydroxylysine for lysine, homoserine for serine, ornithine for lysine, and so forth. Also included are D-amino acids and amino acid derivatives that can alter covalent bonding, for example, the disulfide linkage that forms between two cysteine residues that produces a cyclized polypeptide.

Another example of a modification is the addition of a heterologous domain that imparts a distinct functionality upon either of the two polypeptides or the chimeric polypeptide. A heterologous domain can be any small organic or inorganic molecule or macromolecule, so long as it imparts an additional function. Heterologous domains may or may not affect interaction or affinity between virus coat polypeptide and receptor polypeptide. Particular examples of heterologous domains that impart a distinct function include an amino acid sequence that imparts targeting (*e.g.*, receptor ligand, antibody, etc.), immunopotentiating function (*e.g.*, immunoglobulin, an adjuvant), enable purification, isolation or detection (*e.g.*, myc, T7 tag, polyhistidine, avidin, biotin, lectins, etc.).

Particular heterologous domains exemplified herein include a c-myc polypeptide sequence and an IgG1 heavy chain polypeptide sequence. As exemplified herein, a heterologous domain can have multiple functions. For example, IgG1 can function as an immunopotentiator *in vivo*, as well as function as an adhesive molecule that can be purified, isolated, or detected (*e.g.*, by reaction with a secondary antibody having an enzymatic activity, such as horseradish peroxidase or alkaline phosphatase). The skilled artisan will know of other heterologous domains and can select them as appropriate depending on the application and the function desired.

Thus, in accordance with the present invention, there are provided chimeric polypeptides having one or more heterologous domains. In one embodiment, the heterologous domain is a c-myc polypeptide sequence (glu-gln-lys-leu-ile-ser-glu-glu-asn-leu; SEQ ID NO:1). In another embodiment, the heterologous domain is an immunoglobulin polypeptide sequence comprising heavy chain.

As used herein, the terms "isolated" or "substantially pure," when used as a modifier of invention chimeric polypeptides, sequence fragments thereof, and polynucleotides, means that they are produced by human intervention and are separated from their native *in vivo*

cellular environment. Generally, polypeptides and polynucleotides so separated are substantially free of other proteins, nucleic acids, lipids, carbohydrates or other materials with which they are naturally associated.

Typically, a polypeptide is substantially pure when it is at least 60%, by weight, free from the proteins and other molecules with which it is naturally associated. The preparation is likely at least 75%, more likely at least 90%, and most likely at least 95%, by weight pure. Substantially pure chimeric polypeptide can be obtained, for example, by expressing a polynucleotide encoding the polypeptide in cells and isolating the polypeptide produced. For example, as set forth in the examples, expression of a recombinant polynucleotide encoding a gp120-CD4 polypeptide in mammalian cells allows isolating the chimerical polypeptide from the culture media using an immunoaffinity column. Alternatively, the chimeric polypeptide can be chemically synthesized. Purity can be measured by any appropriate method, *e.g.*, polyacrylamide gel electrophoresis, and subsequent staining of the gel (*e.g.*, silver stain) or by HPLC analysis.

The invention chimeric polypeptides and modifications thereof can be prepared by a variety of methods known in the art. The polypeptide modifications can be introduced by site-directed (*e.g.*, PCR based) or random mutagenesis (*e.g.*, EMS) by exonuclease deletion, by chemical modification, or by fusion of polynucleotide sequences encoding heterologous domain, for example. Chimeric polypeptides can be obtained by expression of a polynucleotide encoding the polypeptide in a host cell, such as a bacteria, yeast or mammalian cell, and purifying the expressed chimeric polypeptide by purification using typical biochemical methods (*e.g.*, immunoaffinity purification, gel purification, expression screening etc). Other well-known methods are described in Deutscher *et al.*, (Guide to Protein Purification: Methods in Enzymology, Vol. 182, Academic Press (1990), which is incorporated herein by reference).

The invention further provides polynucleotides encoding invention chimeric polypeptides, fragments thereof, and complementary sequences. In one embodiment, invention nucleic acids encode the chimeric gp120-CD4 polypeptide exemplified herein. In another embodiment, invention nucleic acids encode gp120-CD4 in which the gp120 has amino acid sequences truncated from the amino and carboxy terminus. In another embodiment, invention nucleic acids encode chimeric gp120-CD4-IgG1.

As used herein, the terms "nucleic acid," "polynucleotide," "oligonucleotide," and "primer" are used interchangeably to refer to deoxyribonucleic acid (DNA) or ribonucleic (RNA), either double- or single-stranded, linear or circular. RNA can be unspliced or spliced mRNA, rRNA, tRNA, or antisense RNAi. DNA can be complementary DNA (cDNA), genomic DNA, or an antisense. Specifically included are nucleotide analogues and derivatives, such as those that are resistant to nuclease degradation, which can function to encode an invention chimeric polypeptide. Nuclease resistant oligonucleotides and polynucleotides are particularly useful for invention nucleic acid vaccines described herein.

An "isolated" or "substantially pure" polynucleotide means that the nucleic acid is not immediately contiguous with the coding sequences with either the 5' end or the 3' end with which it is immediately contiguous in the naturally occurring genome of the organism from which it is derived. The term therefore includes, for example, a recombinant DNA (*e.g.*, a cDNA or a genomic DNA fragment produced by PCR or restriction endonuclease treatment produced during cloning), as well as a recombinant DNA incorporated into a vector, an autonomously replicating plasmid or virus, or a genomic DNA of a prokaryote or eukaryote. It also includes a recombinant DNA part of a chimera or fusion, for example. The term therefore does not include nucleic acids present but uncharacterized among millions of sequences in a genomic or cDNA library, or in a restriction digest of a library fractionated on a gel.

The polynucleotides of the invention also include nucleic acids that are degenerate as a result of the genetic code. There are 20 natural amino acids, most of which are specified by more than one codon. All degenerate polynucleotide sequences are included that encode invention chimeric polypeptides.

Invention polynucleotides can be obtained using standard techniques known in the art (*e.g.*, molecular cloning, chemical synthesis) and the purity can be determined by polyacrylamide or agarose gel electrophoresis, sequencing analysis, and the like. Polynucleotides also can be isolated using hybridization or computer-based techniques that are well known in the art. Such techniques include, but are not limited to: (1) hybridization of genomic DNA or cDNA libraries with probes to detect homologous nucleotide sequences; (2) antibody screening of polypeptides expressed by DNA sequences (*e.g.*, using an expression library); (3) polymerase chain reaction (PCR) of genomic DNA or cDNA using

primers capable of annealing to a nucleic acid sequence of interest; (4) computer searches of sequence databases for related sequences; and (5) differential screening of a subtracted nucleic acid library. Thus, to obtain other receptor encoding polynucleotides, such as those encoding CD4, for example, libraries can be screened for the presence of homologous sequences.

The invention also includes substantially homologous polynucleotides. As used herein, the term "homologous," when used in reference to nucleic acid molecule, refers to similarity between two nucleotide sequences. When a nucleotide position in both of the molecules is occupied by identical nucleotides, then they are homologous at that position. "Substantially homologous" nucleic acid sequences are at least 50% homologous, more likely at least 75% homologous, and most likely 90% or more homologous. As with substantially homologous invention chimeric polypeptides, polynucleotides substantially homologous to invention polynucleotides encoding chimeric polypeptides encode polypeptides that retain most or all of the activity or function associated with the sequence to which it is homologous. For polynucleotides, the length of comparison between sequences will generally be at least 30 nucleotides, alternatively at least 50 nucleotides, more likely at least 75 nucleotides, and most likely 110 nucleotides or more. Algorithms for identifying homologous sequences that account for polynucleotide sequence gaps and mismatched oligonucleotides are known in the art, such as BLAST (see, *e.g.*, Altschul *et al.*, *J. Mol. Biol.* **215**:403-10 (1990)).

In addition, polynucleotides are useful as hybridization probes in order to identify the presence or amount of a polynucleotide encoding a chimeric polypeptide, for example, mRNA (Sambrook *et al.*, Molecular Cloning: A Laboratory Manual, Cold Spring Harbor Laboratory, N.Y. (1989)). Typically such probes are designed to be specific for the desired sequence in order to decrease the probability of hybridizing to unrelated sequences. Such probes can be modified so as to be detectable using radionuclides, luminescent moieties, and so forth.

Hybridization conditions also can be modified in order to achieve the desired specificity. An example of moderately stringent hybridization conditions is as follows: 2X SSC/0.1% SDS at about 37°C or 42°C (hybridization conditions); 0.5X SSC/0.1% SDS at about room temperature (low stringency wash); 0.5X SSC/0.1% SDS at about 42°C

(moderate stringency wash). An example of moderately-high stringency hybridization conditions is as follows: 2X SSC/0.1% SDS at about 37°C or 42°C (hybridization conditions); 0.5X SSC/0.1% SDS at about room temperature (low stringency wash); 0.5X SSC/0.1% SDS at about 42°C (moderate stringency wash); and 0.1 X SSC/0.1% SDS at about 52°C (moderately-high stringency wash). An example of high stringency hybridization conditions is as follows: 2X SSC/0.1% SDS at about 37°C or 42°C (hybridization conditions); 0.5X SSC/0.1% SDS at about room temperature (low stringency wash); 0.5X SSC/0.1% SDS at about 42°C (moderate stringency wash); and 0.1 X SSC/0.1% SDS at about 65°C (high stringency wash).

The polynucleotides of the invention can, if desired, be naked or be in a carrier suitable for passing through a cell membrane (*e.g.*, polynucleotide-liposome complex or a colloidal dispersion system), contained in a vector (*e.g.*, retrovirus vector, adenoviral vectors, and the like), linked to inert beads or other heterologous domains (*e.g.*, antibodies, ligands, biotin, streptavidin, lectins, and the like), or other appropriate compositions disclosed herein or known in the art. Thus, viral and non-viral means of polynucleotide delivery can be achieved and are contemplated. The polynucleotides of the invention also can contain additional nucleic acid sequences linked thereto that encode a polypeptide having a distinct functionality, such as the various heterologous domains set forth herein. Invention polynucleotides also can be modified, for example, to be resistant to nucleases to enhance their stability in a pharmaceutical formulation.

The invention polynucleotides are useful for encoding invention chimeric polypeptides, especially when such polynucleotides are incorporated into expression systems disclosed herein or known in the art. Accordingly, invention polynucleotides including an expression vector are also included.

For propagation or expression in cells, invention polynucleotides can be inserted into a vector. The term "vector" refers to a plasmid, virus, or other vehicle known in the art that can be manipulated by insertion or incorporation of a nucleic acid. Such vectors can be used for genetic manipulation (*i.e.*, "cloning vectors") or can be used to transcribe or translate the inserted polynucleotide (*i.e.*, "expression vectors"). A vector generally contains at least an origin of replication for propagation in a cell and a promoter. Control elements, including promoters present within an expression vector, are included to facilitate proper transcription

and translation (*e.g.*, splicing signal for introns, maintenance of the correct reading frame of the gene to permit in-frame translation of mRNA and stop codons).

*In vivo* or *in vitro* expression of the invention polynucleotides can be conferred by a promoter operably linked to the nucleic acid. "Promoter" refers to a minimal nucleic acid sequence sufficient to direct transcription of the nucleic acid to which the promoter is operably linked (see, *e.g.*, Bitter *et al.*, *Methods in Enzymology*, **153**:516-544 (1987)). Promoters can constitutively direct transcription, can be tissue-specific, or can render inducible or repressible transcription; such elements are generally located in the 5' or 3' regions of the gene so regulated.

In the present invention, for viruses that bind a co-receptor, it is advantageous to introduce and express a polynucleotide encoding a chimeric polypeptide into the cells that are susceptible to viral infection (*e.g.*, cells that express the co-receptor). In this way, the expressed chimeric polypeptide will be secreted by the transformed susceptible cell in close proximity to the co-receptor, thereby inhibiting or preventing access of the virus to the co-receptor which, in turn, inhibits or prevents viral infection of cells. To this end, a tissue-specific promoter can be operably linked to the polynucleotide sequence to confer expression of the chimeric polypeptide in an appropriate target cell.

As used herein, the phrase "tissue-specific promoter" means a promoter that is active in particular cells or tissues that confers expression of the operably linked polynucleotide in the particular cells, *e.g.*, liver cells, hematopoietic cells, or cells of a specific tissue within an animal. The term also covers so-called "leaky" promoters, which regulate expression of a selected DNA primarily in one tissue, but cause expression in one or more other tissues as well.

An inducible promoter can also be used to modulate expression in cells. "Inducible promoter" means a promoter whose activity level increases in response to treatment with an external signal or agent (*e.g.*, metallothionein IIA promoter, heat shock promoter). A "repressible promoter" or "conditional promoter" means a promoter whose activity level decreases in response to a repressor or an equivalent compound. When the repressor is no longer present, transcription is activated or derepressed. Such promoters may be used in combination and also may include additional DNA sequences that are necessary for transcription and expression, such as introns and enhancer sequences.



As used herein, the term “operably linked” means that a selected polynucleotide (*e.g.*, encoding a chimeric polypeptide) and regulatory sequence(s) are connected in such a way as to permit transcription when the appropriate molecules (*e.g.*, transcriptional activator proteins) are bound to the regulatory sequence(s). Typically, a promoter is located 5' of the polynucleotide and may be in close proximity of the transcription initiation site to allow the promoter to regulate expression of the polynucleotide. However, indirect operable linkage is also possible when a promoter on a first vector controls expression of a protein that, in turn, regulates a promoter controlling expression of the polynucleotide on a second vector.

When cloning in bacterial systems, constitutive promoters, such as T7 and the like, as well as inducible promoters, such as pL of bacteriophage gamma, plac, ptrp, ptac, may be used. When cloning in mammalian cell systems, constitutive promoters, such as SV40, RSV and the like, or inducible promoters derived from the genome of mammalian cells (*e.g.*, the metallothionein promoter) or from mammalian viruses (*e.g.*, the mouse mammary tumor virus long terminal repeat, the adenovirus late promoter), may be used. Promoters produced by recombinant DNA or synthetic techniques may also be used to provide for transcription of the nucleic acid sequences of the invention.

Mammalian expression systems that utilize recombinant viruses or viral elements to direct expression may be engineered. For example, when using adenovirus expression vectors, the nucleic acid sequence may be ligated to an adenovirus transcription/translation control complex, *e.g.*, the late promoter and tripartite leader sequence. Alternatively, the vaccinia virus 7.5K promoter may be used (see, *e.g.*, Mackett *et al.*, *Proc. Natl. Acad. Sci. USA*, **79**:7415-7419 (1982); Mackett *et al.*, *J. Virol.*, **49**:857-864 (1984); Panicali *et al.*, *Proc. Natl. Acad. Sci. USA*, **79**:4927-4931 (1982)).

Mammalian expression systems further include vectors specifically designed for “gene therapy” methods, including adenoviral vectors (U.S. Patent Nos. 5,700,470 and 5,731,172), adeno-associated vectors (U.S. Patent No. 5,604,090), herpes simplex virus vectors (U.S. Patent No. 5,501,979), and retroviral vectors (U.S. Patent Nos. 5,624,820, 5,693,508 and 5,674,703 and WIPO publications WO92/05266 and WO92/14829). The chimeric polypeptide encoding gene can be introduced into vaccine delivery vehicles, such as attenuated vaccinia (M. Girard *et al.*, *C R Acad Sci III.*, **322**:959-66 (1999); B. Moss *et al.*, *AIDS*, 2 Suppl 1:S103-5 (1988)), Semiliki-forest virus (M. Girard *et al.*, *C R Acad Sci III.*,

322:959-66 (1999); S.P. Mossman *et al.*, *J. Virol.*, **70**:1953-60 (1996)), or Salmonella (R. Powell *et al.*, In: Molecular Approaches to the control of infectious diseases, pp. 183-187, F. Bran, E. Norrby, D. Burton, and J. Meckalanos (eds), Cold Spring Harbor Press, Cold Spring Harbor, NY (1996); M.T. Shata *et al.*, *Mol Med Today*, **6**:66-71 (2000)) to provide an  
5 efficient and reliable means for the expression of properly associated and folded virus coat protein and receptor sequences, for example, gp120 and CD4. Vectors based on bovine papilloma virus (BPV) have the ability to replicate as extra-chromosomal elements (Sarver *et al.*, *Mol. Cell. Biol.*, **1**:486 (1981)). Shortly after entry of an extra-chromosomal vector into mouse cells, the vector replicates to about 100 to 200 copies per cell. Because  
10 transcription of the inserted cDNA does not require integration of the plasmid into the host's chromosome, a high level of expression occurs. Such vectors also have been employed in gene therapy (U.S. Patent No. 5,719,054). CMV-based vectors also are included (U.S. Patent No. 5,561,063).

For yeast expression, a number of vectors containing constitutive or inducible  
15 promoters may be used (see, *e.g.*, Current Protocols in Molecular Biology, Vol. 2, Ch. 13, ed. Ausubel *et al.*, Greene Publish. Assoc. & Wiley Interscience (1988); Grant *et al.*, "Expression and Secretion Vectors for Yeast," in Methods in Enzymology, Vol. 153, pp. 516-544, eds. Wu & Grossman, 31987, Acad. Press, N.Y. (1987); Glover, DNA Cloning, Vol. II, Ch. 3, IRL Press, Wash., D.C. (1986); Bitter, "Heterologous Gene Expression in  
20 Yeast," Methods in Enzymology, Vol. 152, pp. 673-684, eds. Berger & Kimmel, Acad. Press, N.Y. (1987); and The Molecular Biology of the Yeast Saccharomyces, eds. Strathern *et al.*, Cold Spring Harbor Press, Vols. I and II (1982)). A constitutive yeast promoter, such as ADH or LEU2, or an inducible promoter, such as GAL, may be used ("Cloning in Yeast," R. Rothstein, In: DNA Cloning, A Practical Approach, Vol.11, Ch. 3, ed. D.M. Glover, IRL  
25 Press, Wash., D.C. (1986)). Alternatively, vectors that facilitate integration of foreign nucleic acid sequences into a yeast chromosome, via homologous recombination, for example, are known in the art and can be used. Yeast artificial chromosomes (YAC) are typically used when the inserted polynucleotides are too large for more conventional yeast expression vectors (*e.g.*, greater than about 12 kb).

30 Thus, in accordance with the present invention, polynucleotides encoding invention chimeric polypeptides are provided. The polynucleotides may be inserted into an expression

vector for expression *in vitro* (e.g., using *in vitro* transcription/translation kits, which are available commercially), or may be inserted into an expression vector that contains a promoter sequence that facilitates expression in either prokaryotes or eukaryotes by transfer of an appropriate nucleic acid into a suitable cell, organ, tissue, or organism *in vivo*.

As used herein, a “transgene” is any piece of a polynucleotide inserted by artifice into a host cell, and becomes part of the organism that develops from that cell. A transgene can include one or more promoters and any other DNA, such as introns, necessary for expression of the selected DNA, all operably linked to the selected DNA, and may include an enhancer sequence. A transgene may include a polynucleotide that is partly or entirely heterologous (i.e., foreign) to the transgenic organism, or may represent a gene homologous to an endogenous gene of the organism. Transgenes may integrate into the host cell’s genome or be maintained as a self-replicating plasmid.

As used herein, a “host cell” is a cell into which a polynucleotide is introduced that can be propagated, transcribed, or encoded polypeptide expressed. The term also includes any progeny of the subject host cell. It is understood that all progeny may not be identical to the parental cell, since there may be mutations that occur during replication.

Host cells include but are not limited to bacteria, yeast, insect, and mammalian cells. For example, bacteria transformed with recombinant bacteriophage polynucleotide, plasmid nucleic acid, or cosmid nucleic acid expression vectors; yeast transformed with recombinant yeast expression vectors; plant cell systems infected with recombinant virus expression vectors (e.g., cauliflower mosaic virus, CaMV; tobacco mosaic virus, TMV), or transformed with recombinant plasmid expression vectors (e.g., Ti plasmid), insect cell systems infected with recombinant virus expression vectors (e.g., baculovirus), or animal cell systems infected with recombinant virus expression vectors (e.g., retroviruses, adenovirus, vaccinia virus), or transformed animal cell systems engineered for stable expression.

For long-term expression of invention polypeptides, stable expression is preferred. Thus, using expression vectors containing viral origins of replication, for example, cells can be transformed with a nucleic acid controlled by appropriate control elements (e.g., promoter/enhancer sequences, transcription terminators, polyadenylation sites, etc.).

Although not wishing to be bound or so limited by any particular theory, stable maintenance of expression vectors in mammalian cells is believed to occur by integration of the vector

into a chromosome of the host cell. Optionally, the expression vector also can contain a nucleic acid encoding a selectable marker conferring resistance to a selective pressure or reporter indicating the cells into which the gene has been introduced, thereby allowing cells having the vector to be identified, grown, and expanded. As used herein, "reporter gene" means a gene whose expression may be assayed; such genes include, without limitation, *lacZ*, amino acid biosynthetic genes, *e.g.* the yeast *LEU2* gene, luciferase, or the mammalian chloramphenicol transacetylase (CAT) gene. Reporter genes may be integrated into the chromosome or may be carried on autonomously replicating plasmids (*e.g.*, yeast 2 micron plasmids). Alternatively, the selectable marker can be on a second vector cotransfected into a host cell with a first vector containing an invention polynucleotide.

A number of selection systems may be used, including, but not limited to the *neomycin* gene, which confers resistance to the aminoglycoside G418 (Colberre-Garapin *et al.*, *J. Mol. Biol.*, **150**:1 (1981)) and the *hygromycin* gene, which confers resistance to hygromycin (Santerre *et al.*, *Gene*, **30**:147 (1984)). Recently, additional selectable genes have been described, namely *trpB*, which allows cells to utilize indole in place of tryptophan; *hisD*, which allows cells to utilize histinol in place of histidine (Hartman *et al.*, *Proc. Natl. Acad. Sci. USA*, **85**:8047 (1988)); and ODC (ornithine decarboxylase), which confers resistance to the ornithine decarboxylase inhibitor, 2-(difluoromethyl)-DL-ornithine, DFMO (McConlogue, In: Current Communications in Molecular Biology, Cold Spring Harbor Laboratory, ed. (1987)).

As used herein, the term "transformation" means a genetic change in a cell following incorporation of a polynucleotide (*e.g.*, a transgene) exogenous to the cell. Thus, a "transformed cell" is a cell into which, or a progeny of which, a polynucleotide has been introduced by means of recombinant techniques. Transformed cells do not include an entire human being. Transformation of a host cell may be carried out by conventional techniques known to those skilled in the art. When the host cell is a eukaryote, methods of DNA transformation include, for example, calcium phosphate, microinjection, electroporation, liposomes, and viral vectors. Eukaryotic cells also can be co-transformed with invention polynucleotide sequences or fragments thereof, and a second DNA molecule encoding a selectable marker, as described herein or otherwise known in the art. Another method is to use a eukaryotic viral vector, such as simian virus 40 (SV40) or bovine papilloma virus, to

transiently infect or transform eukaryotic cells, and express the protein (see, *e.g.*, Eukaryotic Viral Vectors, Cold Spring Harbor Laboratory, Gluzman ed. (1982)). When the host is prokaryotic (*e.g.*, *E. coli*), competent cells that are capable of DNA uptake can be prepared from cells harvested after exponential growth phase and subsequently treated by the CaCl<sub>2</sub> method using procedures well-known in the art. Transformation of prokaryotes also can be performed by protoplast fusion of the host cell.

Invention chimeric polypeptides, polynucleotides, and expression vectors containing same can be encapsulated within liposomes using standard techniques and introduced into cells or whole organisms. Cationic liposomes are preferred for delivery of polynucleotides. The use of liposomes for introducing various compositions *in vitro* or *in vivo*, including proteins and polynucleotides, is known to those of skill in the art (see, for example, U.S. Patent Nos. 4,844,904, No. 5,000,959, No. 4,863,740 and 4,975,282).

Liposomes can be targeted to a cell type or tissue of interest by the addition to the liposome preparation of a ligand, such as a polypeptide, for which a corresponding cellular receptor has been identified. For example, in the case of a virus that infects a CD4+ cell, CD4+ cells are an appropriate target and HIV gp120 could be an appropriate ligand for intracellular introduction of a liposome containing an invention chimeric polypeptide or polynucleotide sequence. Monoclonal antibodies also can be used for targeting; many such antibodies specific for a wide variety of cell surface proteins are known to those skilled in the art and are available. The selected ligand is covalently conjugated to a lipid anchor in either preformed liposomes or are incorporated during liposome preparation (see Lee & Low, *J. Biol. Chem.*, **269**:3198 (1994); Lee & Low *Biochim. Biophys. Acta*, **1233**:134 (1995)).

The invention chimeric polypeptides and polynucleotides encoding same can be introduced into a whole organism. In particular, for chimeric polypeptides that contain a virus coat polypeptide that binds to co-receptor, transgenic animals expressing invention chimeric polypeptides would be useful for studying the long-term effects of chimeric expression, as well as determining whether the expressed chimeric polypeptide could protect or inhibit infection by a corresponding virus.

Thus, in another embodiment, the invention provides non-human transgenic animals that express chimeric polypeptides. Preferred animals are susceptible to viral infection for which a corresponding receptor polypeptide sequence is known. Preferred animals are those

susceptible to immunodeficiency virus infection, including mammals, such as non-human primates (e.g., macaques, chimpanzees, apes, gibbons, orangutans, etc.), domestic animals, and livestock, as described herein.

The term "transgenic animal" refers to any animal whose somatic or germ line cells bear genetic information received, directly or indirectly, by deliberate genetic manipulation at the subcellular level, such as by microinjection or infection with recombinant virus. The term "transgenic" further includes cells or tissues (*i.e.*, "transgenic cell," "transgenic tissue") obtained from a transgenic animal genetically manipulated, as described herein. In the present context, a "transgenic animal" does not encompass animals produced by classical crossbreeding or *in vitro* fertilization, but rather denotes animals in which one or more cells receive a recombinant DNA molecule. Invention transgenic animals can be either heterozygous or homozygous with respect to the transgene. Methods for producing transgenic animals are well known in the art (see, for example, U.S. Patent Nos. 5,721,367, 5,695,977, 5,650,298, and 5,614,396).

Invention chimeric polypeptides can be used to generate additional reagents, such as antibodies. Invention antibodies are useful in the various treatment methods set forth herein. For example, the antibody produced in an immunized subject can protect the subject against virus infection or, alternatively, be transferred to a recipient subject, thereby passively protecting the second subject against infection. Antibodies that bind to an epitope exposed upon complex formation between a virus coat polypeptide sequence and a receptor polypeptide sequence also can be generated. In addition, invention antibodies are useful in diagnostic methods, purification methods, and in screening methods (*e.g.*, identifying cryptic epitopes, co-receptors, etc.), as disclosed herein.

Thus, in accordance with the present invention, antibodies that bind to chimeric polypeptides, including antibodies specific for cryptic epitopes exposed upon complex formation as set forth herein, are provided. In one embodiment, the antibody neutralizes multiple viral isolates and viruses from different geographic clades (termed "broadly neutralizing") *in vitro*. In another embodiment, the antibody inhibits, prevents, or blocks virus infection *in vitro* or *in vivo*. In various aspects of these embodiments, the virus neutralized is an immunodeficiency virus, including the HIV-1 and HIV-2 immunodeficiency viruses set forth herein. Antibody comprising polyclonal antibodies, pooled monoclonal

antibodies with different epitopic specificities, and distinct monoclonal antibody preparations, also are provided.

Antibodies to chimeric polypeptide are produced by administering a chimeric polypeptide to an animal. The antibodies can be produced, isolated, and purified using methods well-known in the art. Thus, in another embodiment, the invention provides methods for producing an antibody to a chimeric polypeptide. A method of the invention includes administering a chimeric polypeptide to a subject and isolating the antibodies that bind to the chimeric polypeptide. In one embodiment, the antibody produced binds to a cryptic epitope exposed upon the binding between a virus coat polypeptide sequence and a receptor polypeptide sequence.

Invention antibodies can preferentially bind to cryptic epitopes exposed when the virus coat polypeptide sequence (*e.g.*, envelope polypeptide sequence) and the receptor polypeptide sequence bind to each other. For example, the HIV envelope polypeptide sequence gp120 exposes a cryptic epitope upon binding to CD4 receptor polypeptide sequence, and antibodies to the exposed epitope can lead to broad neutralization of HIV. Such epitopes may be shared among different viral isolates and geographic clades accounting for broad-spectrum neutralizing activity of the antibodies directed to these epitopes.

Although not wishing to be bound by theory, it appears that in the absence of CD4 binding, the cryptic epitope is not exposed or is not antigenic. As used herein, the term "epitope" refers to an antigenic determinant on an antigen to which the paratope of an antibody binds. Epitopic determinants usually consist of chemically active surface groupings of molecules, such as amino acids or carbohydrate side chains, and usually have specific three-dimensional structural characteristics, as well as specific charge characteristics. As used herein, the term "cryptic" refers to a property or feature that requires a structural or conformational change for the feature or property to become apparent; in the absence of the change, the feature or property is "hidden." Cryptic epitopes may be present on either virus coat protein or receptor polypeptide sequences.

The term "antibody" includes intact molecules, as well as fragments thereof, such as Fab, F(ab')<sub>2</sub>, and Fv, which are capable of binding to an epitopic determinant present in an invention chimeric polypeptide. Other antibody fragments are included, so long as the fragment retains the ability to selectively bind with its antigen. Antibody fragments (*e.g.*,

Fab, F(ab')<sub>2</sub>, and Fv) of the present invention can be prepared by proteolytic hydrolysis of the antibody, for example, by pepsin or papain digestion of whole antibodies.

Antibodies which bind to invention chimeric polypeptides can be prepared using intact chimeric polypeptide or fragments thereof as the immunizing antigen. In the case of chimeric polypeptide fragments, it is preferred that the virus coat polypeptide sequence and the receptor polypeptide sequence maintain the ability to bind each other so that any cryptic epitopes present will be exposed. The chimeric polypeptide used to immunize an animal is derived from translated polynucleotide or is chemically synthesized and, if desired, can be conjugated to a carrier. Such commonly used carriers chemically coupled to the immunizing peptide include, for example, keyhole limpet hemocyanin (KLH), thyroglobulin, bovine serum albumin (BSA), and tetanus toxoid.

Monoclonal antibodies are made by methods well-known to those skilled in the art (Kohler *et al.*, *Nature*, **256**:495 (1975); and Harlow *et al.*, Antibodies: A Laboratory Manual, p. 726, eds. Cold Spring Harbor Pub. (1988), which are incorporated herein by reference). Briefly, monoclonal antibodies can be obtained by injecting mice with a composition comprising an antigen, verifying the presence of antibody production by analyzing a serum sample, removing the spleen to obtain B lymphocytes, fusing the B lymphocytes with myeloma cells to produce hybridomas, cloning the hybridomas, selecting positive clones that produce antibodies to the antigen, and isolating the antibodies from the hybridoma cultures. Monoclonal antibodies can be isolated and purified from hybridoma cultures by a variety of well-established techniques, which include; for example, affinity chromatography with Protein-A Sepharose, size-exclusion chromatography, and ion-exchange chromatography (see, *e.g.*, Coligan *et al.*, "Production of Polyclonal Antisera in Rabbits, Rats, Mice and Hamsters," In: Current Protocols in Immunology, §§ 2.7.1-2.7.12 and §§ 2.9.1-2.9.3; and Barnes *et al.*, "Purification of Immunoglobulin G (IgG)," In: Methods in Molecular Biology, Vol. 10, pp. 79-104, Humana Press (1992)). The preparation of polyclonal antibodies is well-known to those skilled in the art (see, *e.g.*, Green *et al.*, "Production of Polyclonal Antisera," In: Immunochemical Protocols, pp. 1-5, Manson, ed., Humana Press (1992); Harlow *et al.* (1988), *supra*; and Coligan *et al.* (1992), *supra*, § 2.4.1, which are incorporated herein by reference).



For therapeutic purposes, antibody to a chimeric polypeptide produced in one species can be humanized so that the antibody does not induce an immune response when administered to the host, for example, for passive immunization. Generally, humanized antibodies are produced by replacing a non-human constant region with a human constant region. Such antibody humanization methods are known in the art and are particularly useful in the methods of the invention (Morrison *et al.*, *Proc. Natl. Acad. Sci. USA*, **81**:6851 (1984); Takeda *et al.*, *Nature*, **314**:452 (1985); Singer *et al.*, *J. Immunol.*, **150**:2844 (1993)).

Invention antibodies that bind chimeric polypeptide, particularly, antibodies that bind a cryptic epitope, can neutralize the virus *in vitro* or *in vivo* (*i.e.*, in a subject). Such antibodies can therefore prevent or inhibit virus infection *in vitro* or *in vivo*, and may ameliorate some or all of the symptoms associated with the infection. Such antibodies can be produced in one subject and then introduced into another, *i.e.*, for passive immunotherapy. Alternatively, antibodies that bind chimeric polypeptides, when produced in a subject, can protect that subject from infection or ameliorate some or all of the symptoms associated with the infection.

Thus, in accordance with the present invention, there are provided methods for inhibiting, preventing, and ameliorating a viral infection in a subject. In one embodiment, a method of the invention includes administering an effective amount of an antibody that binds to a chimeric polypeptide to a subject, thereby preventing or inhibiting virus infection in the subject. In another embodiment, a method of the invention includes administering an effective amount of a chimeric polypeptide to a subject, thereby producing an immune response sufficient for preventing or inhibiting virus infection in the subject. In yet another embodiment, a method of the invention includes administering to a subject an effective amount of a polynucleotide encoding an invention chimeric polypeptide. In various aspects, the chimeric polypeptide contains an immunodeficiency virus envelope polypeptide, as disclosed herein.

In the methods for inhibiting, preventing, and ameliorating a viral infection in a subject in which a chimeric polypeptide or a polynucleotide encoding a chimeric polypeptide are administered, an immune response also can be produced. The immune response will likely be humoral in nature, although a administering a polynucleotide encoding a chimeric

polypeptide may induce a CTL response. It is also understood that the methods of the invention can also be used in combination with other viral therapies, as appropriate.

The "effective amount" will be sufficient to inhibit, prevent, or ameliorate a viral infection in a subject, or will be sufficient to produce an immune response in a subject. Thus, an effective amount of chimeric polypeptide can be that which elicits an immune response to the polypeptide or a virus upon which the coat protein is based. An effective amount administered to a subject already infected with the virus can also be that which decreases viral load, or increases the number of CD4+ cells. An effective amount can be that which inhibits transmission of the virus from an infected subject to another (uninfected or infected). In the methods of the invention in which a polynucleotide sequence encoding a chimeric polypeptide is administered to a subject, a CTL response to the chimeric polypeptide can be produced against a virus that contains the corresponding coat polypeptide sequence.

As the invention chimeric polypeptides, polynucleotides, and antibodies will be administered to subjects, including humans, the present invention also provides pharmaceutical formulations comprising invention chimeric polypeptides, polynucleotides, and antibodies. The compositions administered to a subject will therefore be in a "pharmaceutically acceptable" or "physiologically acceptable" formulation.

As used herein, the terms "pharmaceutically acceptable" and "physiologically acceptable" refer to carriers, diluents, excipients, and the like that can be administered to a subject, preferably without excessive adverse side effects (*e.g.*, nausea, headaches, etc.). Such preparations for administration include sterile aqueous or non-aqueous solutions, suspensions, and emulsions. Examples of non-aqueous solvents are propylene glycol, polyethylene glycol, vegetable oils, such as olive oil, and injectable organic esters, such as ethyl oleate. Aqueous carriers include water, alcoholic/aqueous solutions, emulsions, or suspensions, including saline and buffered media. Vehicles include sodium chloride solution, Ringer's dextrose, dextrose and sodium chloride, lactated Ringer's or fixed oils. Intravenous vehicles include fluid and nutrient replenishers, electrolyte replenishers (such as those based on Ringer's dextrose), and the like. Preservatives and other additives may also be present, such as, for example, antimicrobial, anti-oxidants, chelating agents, and inert gases and the like. Various pharmaceutical formulations appropriate for administration to a subject known in the art are applicable in the methods of the invention (*e.g.*, Remington's

Pharmaceutical Sciences, 18th ed., Mack Publishing Co., Easton, PA (1990); and The Merck Index, 12th ed., Merck Publishing Group, Whitehouse, NJ (1996)).

Controlling the duration of action or controlled delivery of an administered composition can be achieved by incorporating the composition into particles or a polymeric substance, such as polyesters, polyamine acids, hydrogel, polyvinyl pyrrolidone, ethylene-vinylacetate, methylcellulose, carboxymethylcellulose, protamine sulfate or lactide/glycolide copolymers, polylactide/glycolide copolymers, or ethylenevinylacetate copolymers. The rate of release of the composition may be controlled by altering the concentration or composition of such macromolecules. For example, it is possible to entrap an arginine framed tripeptide sequence in micro-capsules prepared by coacervation techniques or by interfacial polymerization, for example, by the use of hydroxymethylcellulose or gelatin-microcapsules or poly (methylmethacrolate) microcapsules, respectively, or in a colloid drug delivery system. Colloidal dispersion systems include macromolecule complexes, nano-capsules, microspheres, beads, and lipid-based systems, including oil-in-water emulsions, micelles, mixed micelles, and liposomes.

The compositions administered by a method of the invention can be administered parenterally by injection, by gradual perfusion over time, or by bolus administration (for example, in the case of passive protection against HIV infection resulting from a needlestick injury) or by a microfabricated implantable device. The composition can be administered via inhalation, intravenously, intraperitoneally, intramuscularly, subcutaneously, intracavity (e.g., vaginal or anal), transdermally, topically, or intravascularly. The compositions can be administered in multiple doses. The doses or "effective amount" needed for treating, inhibiting, or preventing viral infection or transmission, or for inducing an immune response, preferably will be sufficient to ameliorate some or all of the symptoms of the infection, although preventing progression or worsening of the infection also is a satisfactory outcome for many viral infections, including HIV. An effective amount can readily be determined by those skilled in the art (see, for example, Ansel *et al.*, Pharmaceutical Drug Delivery Systems, 5th ed. (Lea and Febiger (1990), Gennaro ed.)).

The chimeric polypeptides, polynucleotides, and antibodies of the invention also are useful for diagnostic purposes. For example, a chimeric polypeptide having a virus coat polypeptide sequence derived from a virus that utilizes co-receptor for infection can be used

to identify subjects that express co-receptors having decreased binding affinity for the chimeric polypeptide. Subjects which have a decreased binding affinity will likely have a decreased risk of infection by the virus. Alternatively, subjects expressing co-receptors having an increased binding affinity for the chimeric polypeptide will likely be at increased risk of virus infection. In this way, subjects having decreased or increased risk to virus infection can be identified. For example, subjects expressing a CCR5 or CXCR4 co-receptor having increased or decreased affinity for a chimeric polypeptide comprised of HIV gp120-CD4 will be at increased or decreased risk of HIV infection, respectively. Accordingly, such methods also are useful for assessing prognosis; subjects expressing a high affinity binding co-receptor likely having a poorer prognosis.

In the case of invention chimeric polypeptides that have a virus coat polypeptide sequence of a virus that utilizes a co-receptor, such chimeric polypeptides are useful for identifying agents that modulate binding of the virus to the co-receptor. Such invention chimeric polypeptides also are useful for identifying agents that modulate the intramolecular interaction/binding of the virus coat polypeptide sequence to the receptor sequence within the chimeric polypeptide. Thus, invention chimeric polypeptides that contain coat polypeptide of virus that may not utilize co-receptor can be used to identify agents that modulate binding of the coat sequence to the receptor sequence within the chimeric molecule.

Thus, in accordance with the present invention, there are provided methods for identifying an agent that modulate binding between a virus and a virus co-receptor, and methods for identifying an agent that modulate binding between a virus and a virus receptor. In one embodiment, a method of the invention includes contacting a chimeric polypeptide with a co-receptor polypeptide under conditions allowing the chimeric polypeptide and the co-receptor polypeptide to bind, in the presence and absence of a test agent, and detecting binding in the presence and absence of the test agent. In another embodiment, a method of the invention includes contacting a chimeric polypeptide that forms an intramolecular complex with a test agent, and detecting binding between the virus coat polypeptide sequence and the receptor polypeptide sequence within the chimera. A decreased amount of binding in the presence of the test agent thereby identifies an agent that inhibits interaction/binding between the virus and the virus co-receptor or receptor. Increased binding in the presence of

the test agent thereby identifies an agent that stimulates interaction/binding between the virus and the virus co-receptor or receptor.

The contacting can occur in solution, solid phase, on intact cells, or in an organism, such as a non-human primate. In various embodiments, the virus is an immunodeficiency virus, such as HIV, and the co-receptor is a chemokine, such as CCR5 or CXCR4.

The binding of viruses that utilize co-receptors for cell penetration is a critical step for subsequent infection, viral proliferation, and the ultimate pathological symptoms resulting therefrom. Thus, in another embodiment, methods for identifying agents that inhibit virus cell penetration, infection, and proliferation, as well as agents that ameliorate the symptoms associated with the virus infection, are provided. In a method of the invention for identifying such agents, the test agent can be added after contacting the chimeric polypeptide with the co-receptor polypeptide or, alternatively, before contacting the chimeric polypeptide with the co-receptor polypeptide.

Candidate agents include antibodies, antivirals, a co-receptor polypeptide sequence (e.g., from CCR5 or CXCR4), peptidomimetics or active fragments thereof. Candidate agents also encompass numerous chemical classes, including organic molecules, like small organic compounds having a molecular weight of more than 50 and less than about 2,500 daltons. Candidate agents comprise functional groups necessary for structural interaction with proteins, particularly hydrogen bonding, and typically include at least an amine, carbonyl, hydroxyl, or carboxyl group, preferably at least two of the functional chemical groups. The candidate agents often comprise cyclical carbon or heterocyclic structures, and/or aromatic or polyaromatic structures substituted with one or more of the above functional groups. Candidate agents are also found among biomolecules, including, but not limited to, peptides, saccharides, fatty acids, steroids, purines, pyrimidines, derivatives, structural analogs, or combinations thereof.

Candidate agents are obtained from a wide variety of sources, including libraries of synthetic or natural compounds. For example, numerous means are available for random and directed synthesis of a wide variety of organic compounds and biomolecules, including expression of randomized oligonucleotides and oligopeptides. Alternatively, libraries of natural compounds in the form of bacterial, fungal, plant, and animal extracts are available or readily produced. Additionally, natural or synthetically produced libraries and compounds

are readily modified through conventional chemical, physical, and biochemical means, and may be used to produce combinatorial libraries. Known pharmacological agents may be subjected to directed or random chemical modifications, such as acylation, alkylation, esterification, amidification, etc., to produce structural analogs.

5 Where the method detects binding, one or more of the molecules may be joined to a label, where the label can directly or indirectly provide a detectable signal. Various labels include radioisotopes, fluorescers, chemilumescers, enzymes, specific binding molecules, particles, *e.g.* magnetic particles, and the like. Specific binding molecules include pairs, such as biotin and streptavidin, digoxin and antidigoxin, etc. For the specific binding members,  
10 the complementary member would normally be labeled with a molecule that provides for detection, in accordance with known procedures.

A variety of other reagents may be included in the assay. These include reagents, like salts, neutral proteins, *e.g.* albumin, detergents, etc., that are used to facilitate optimal protein-protein binding and/or reduce non-specific or background interactions. Reagents that  
15 improve the efficiency of the assay, such as protease inhibitors, nuclease inhibitors, anti-microbial agents, etc., may be used. The mixture of components are added in any order that provides for the requisite binding. Incubations are performed at any suitable temperature, typically between 4 and 40°C. Incubation periods are selected for optimum activity, but may also be optimized to facilitate rapid high-throughput screening. Typically, between 0.1 and 1  
20 hours will be sufficient.

In various embodiments, the virus is an immunodeficiency virus, as described herein, such as HIV, HTLV, SIV, FeLV, FPV, or herpes virus. In other embodiments, the contacting occurs in solution, solid phase, on an intact cell, or in an animal, such as a non-human primate, as described herein. In additional embodiments, the co-receptor is a CCR5,  
25 CXCR4, CCR-2b, CCR3, CCR8, V28/CX3CR1, US28 (herpes virus encoded chemokine like receptor), STRL33/BOB/TYMSTR, GPR15/Bonzo, or GPR1 polypeptide sequence.

An agent identified by a method of the invention described herein can be further tested for its ability to inhibit virus binding or infection of a cell *in vitro* or *in vivo*. Thus, in accordance with the present invention, there are provided methods for identifying an agent  
30 that inhibits virus infection of a cell. A method of the invention includes contacting a cell susceptible to virus infection with an infectious virus particle in the presence and absence of

a test agent, and determining whether the test agent inhibits virus binding or infection of the cell, thereby identifying an agent that inhibits virus infection. In various embodiments, the test agent is added before or after contacting the cell with the infectious virus particle. The method also can be performed in any suitable animal, such as a non-human primate.

The invention chimeric polypeptides also are useful for identifying novel co-receptors or characterizing proteins as co-receptors. In this way, viral infection and subsequent pathogenesis for any virus can be better understood, thereby enabling improved treatment of the infection. For example, one method for identifying a novel co-receptor or characterizing co-receptor function is the two-hybrid system, which can detect protein-protein interactions through the activation of a reporter whose expression is induced by interacting polypeptides. Thus, an appropriate chimeric polypeptide can be used as a bait sequence in a yeast or mammalian two-hybrid system to screen a library for the purpose of identifying interacting proteins, including novel co-receptors. Well established biochemical methods of detecting protein-protein interactions (e.g., column chromatography, gradient centrifugation, co-immunoprecipitation analysis, etc.) also are applicable in identifying co-receptors or in characterizing proteins as having potential co-receptor function.

The chimeric polypeptides that bind co-receptors also are useful for identifying a co-receptor binding site. For example, by producing co-receptor polypeptide fragments and contacting the fragments with an appropriate chimeric polypeptide. The contacting can be done in solution, (e.g., co-precipitation), solid phase (e.g., affinity column), or on an intact cell (e.g., contacting co-receptor fragments on a cell surface and detecting whether the co-receptor fragment inhibits chimeric polypeptide binding to the cell). A co-receptor binding site, once identified, can be used as an antiviral agent to treat infection, for example.

Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. Although methods and materials similar or equivalent to those described herein can be used in the practice or testing of the present invention, suitable methods and materials are described below. All publications, patent applications, patents, and other references mentioned herein are incorporated by reference in their entirety. In case of conflict, the present specification, including definitions, will control. In addition, the materials, methods, and examples are illustrative only and are not intended to be limiting. Other features and

advantages of the invention will be apparent from the following detailed description, and from the claims. The invention is further described in the following examples, which do not limit the scope of the invention(s) described in the claims.

### EXAMPLE I

This Example describes the construction of a polynucleotide encoding a single chain gp120-CD4 chimeric polypeptide FLSC or TcSC.

The strategy for building a single chain complex is based on the placement of a 20 to 30 amino acid linker sequence between the C terminus of gp120 and the N terminus of CD4. Analyses of the crystal structure of modified gp120 bound to soluble CD4 and 17b Fab (Dwong, P.D. *et al.*, *Nature*, **393**:648-59 (1998)) using Swiss PDB Viewer suggested that a chimeric molecule should be capable of intramolecular interactions leading to formation of a gp120-CD4 complex.

A single chain nucleic acid encoding a gp120-CD4 chimeric polypeptide was constructed by arranging the respective coding sequences in the following order: (1) at the 5' end, a synthetic, codon encoding gp120 of the macrophage-tropic HIVs, BaL; (2) a sequence encoding a 20 amino acid linker consisting of glycines, alanine, and serines; (3) sequences for soluble CD4 domains 1 and 2 (D1D2); and (4) at the 3' end, sequences encoding a short polypeptide derived from the c-myc oncogene. The codon optimized gp120 sequence was used as it permits high-level expression in a rev-independent manner (Haas, J., *et al.*, *Curr. Biol.*, **6**:315-24 (1996)). The human CD4 sequence used was derived from T4-pMV7 (Maddon, P. J., *et al.*, *Cell*, **47**:333-48 (1986); NIH AIDS Reagent Repository, Bethesda, MD). The myc polypeptide sequence allows convenient analyses, purification, and other manipulation of the chimeric polypeptide.

A complete polynucleotide comprising these sequences was generated by PCR and inserted into pEF6 (Invitrogen) using the strong elongation factor promoter (EF1<sup>α</sup>) to drive expression. Restriction enzyme sites were introduced into this construct (designated pEF6-SC<sup>BaL</sup>) to permit convenient exchange with other envelope genes of other immunodeficiency viruses.

Briefly, FLSC molecule was constructed via PCR using the plasmids pMR1W1-9 and T4-pMV7 as templates. The gp120 forward primer was GGG-GGT-ACC-ATG-CCC-ATG-



GGG-TCT-CTG-CAA-CCG-CTG-GCC (SEQ ID NO:2) and the reverse primer was GGG-TCC-GGA-GCC-CGA-GCC-ACC-GCC-ACC-AGA-GGA-TCC-ACG-CTT-CTC-GCG-CTG-CAC-CAC-GCG-GCG-CTT (SEQ ID NO:3). The CD4 forward primer was GGG-TCC-GGA-GGA-GGT-GGG-TCG-GGT-GGC-GGC-GCG-GCC-GCT-AAG-AAA-GTG-GTG-CTG-GGC-AAA-AAA-GGG-GAT (SEQ ID NO:4) and the reverse primer was GGG-GTT-TAA-AC-TTA-TTA-CAG-ATC-CTC-TTC-TGA-GAT-GAG-TTT-TTG-TTC-AGC-TAG-CAC-CAC-GAT-GTC-TAT-TTT-GAA-CTC (SEQ ID NO:5). The PCR product was subcloned into pEF6 (Invitrogen, Carlsbad, CA) using *Kpn*I and *Pme*I restriction sites. To construct the pEF6-TcSC plasmid, the full-length gp120 expressing sequence in pEF6-FLSC was exchanged for a truncated version of the gp120 sequence (DC1DC5DV1V2). The truncated gp120 was generated using GGG-GGT-ACC-ATG-CCC-ATG-GGG-TCT-CTG-CAA-CCG-CTG-GCC-ACC-TTG-TAC-CTG-CTG-GGG-ATG-CTG-GTC-GCT-TCC-TGC-CTC-GGA-AAG-AAC-GTG-ACC-GAG-AAC-TTC-AAC-ATG-TGG (SEQ ID NO:6) as a forward primer and GGG-GGA-TCC-GAT-CTT-CAC-CAC-CTT-GAT-CTT-GTA-CAG-CTC (SEQ ID NO:7) as a reverse primer. The V1 and V2 regions were deleted using CTG-TGC-GTG-ACC-CTG-GGC-GCG-GGC-GAG-ATG-AAG-AAC-TGC-AGC-TTC-AAC-ATC-GGC-GCG-GGC-CGC-CTG-ATC-AGC-TGC (SEQ ID NO:8) as a forward primer and GCA-GCT-GAT-CAG-GCG-GCC-CGC-GCC-GAT-GTT-GAA-GCT-GCA-GTT-CTT-CAT-CTC-GCC-CGC-GCC-CAG-GGT-CAC-GCA-CAG (SEQ ID NO:9) as a reverse primer.

The recombinant constructs are shown in FIG. 1. The chimeric recombinant which contained the entire BaL gp120 sequence was designated full-length single chain (FLSC). A second construct was designed to produce complexes more closely resembling the molecules used to solve the gp120 crystal structure. This construct was designated truncated single chain (TcSC) and constructed as with FLSC except that a sequence encoding  $\Delta$ C1 $\Delta$ C5 $\Delta$ V1V2 gp120 was used in place of the full length coding sequence. The amino acid sequence of the spacer region is GSSGGGSGSGGGGSGGGAAA (SEQ ID NO:10)

## **EXAMPLE II**

This Example describes the transfection of cells with the polynucleotide encoding the gp120-CD4 chimeric polypeptide and the characterization of the expressed soluble polypeptide.

Recombinant pEF6-FLSC or pEF6-TcSC was transfected into 293 cells using  
 5 Eugene, according to the manufacturer's protocol (Boehringer-Manheim). Stable  
 transfectants were obtained by selection with 5µg/ml blasticidin. A stable cell line (293-SC)  
 was cultured under different conditions, and the production of chimeric polypeptide  
 evaluated by immunoblot analysis using a mixture of our anti-gp120 monoclonal antibodies  
 (Y.H. Abacioglu *et al.*, *AIDS Res. Hum. Retroviruses*, 10:371-81 (1994)) or anti- human CD4  
 10 polyclonal sera (T4-4) (K. C. Deen *et al.*, *Nature*, 331:82-4 (1998); R. L. Willey *et al.*, *J.*  
*Virol.*, 66:226-34 (1992); NIH AIDS Reagent Repository).

Briefly, cell culture supernatants containing the chimeric polypeptide were collected  
 and boiled in SDS-PAGE loading buffer (75 mM Tris, 2% SDS, 10% glycerol, 0.001%  
 bromphenol blue, pH 8.3). The samples were then electrophoresed in a 4-20% SDS-  
 15 polyacrylamide gradient gel. The gel-fractionated proteins were then transferred to a  
 nitrocellulose membrane. Non-specific binding sites on the membrane were then blocked for  
 30 minutes with 2% non-fat dry milk in tris-buffered saline, pH 7. The membrane was then  
 probed with either anti-CD4 polyclonal rabbit sera (T4-4; NIH AIDS Reagent Repository,  
 Bethesda, MD) or a mixture of murine monoclonal antibody against HIV gp120.

As shown in FIG. 2, the transfected cells expressed a soluble protein of the expected  
 size (150kD). This polypeptide was reactive with both anti-gp120 and anti-CD4 antibodies  
 and, thus, represented intact chimeric polypeptide. In other studies, reactivity with anti-myc  
 antibody was detected further confirming the identity of the 150 kD species as the chimeric  
 polypeptide. In addition to this polypeptide, bands matching the expected sizes for gp120  
 25 and CD4 D1D2/myc tag were observed indicating that a portion of the chimeric polypeptide  
 had been cleaved at the spacer. Addition of a biologically compatible protease inhibitor  
 (Pefabloc; Boehringer-Mannhiem) yielded essentially uncleaved chimeric polypeptide  
 molecules. This suggests that cleavage of gp120-CD4 occurs by a serine protease.

The amount of gp120-CD4 chimeric polypeptide produced by the 293-SC cell line  
 30 was determined using an anti-gp120 capture ELISA with sheep anti-gp120 antibody D7324  
 (International Enzymes), a sheep polyclonal IgG against a highly conserved epitope in the

gp120C5 region (J.P. Moore, *AIDS*, 4:297-305 (1990); J.P. Moore *et al.*, *J. Virol.*, 67:863-75 (1992); J. P. Moore *et al.*, *AIDS*, 4:307-15 (1990)), and a gp120 standard curve. Briefly, 2 ug/ml of D7324 in phosphate-buffered saline was absorbed onto a plastic plate. Non-specific binding sites were blocked with 2% non-fat dry milk in tris-buffered saline.

5 Saturating concentrations of cell culture supernatant from the 293-SC line were then added to the plate. Captured chimeric polypeptide was detected using inactivated human sera from HIV-infected patients and anti-human IgG conjugated to horse-radish peroxidase. The 293-SC cell line is estimated to secrete approximately 3 ug/ml of gp120-CD4 chimeric polypeptide. The 293-SC cell line has been adapted to grow in serum-free conditions.

10 Because the immunoblotting studies indicated that there was some cleavage of the gp120-CD4 chimeric polypeptide a sample of purified single chain was crosslinked and the crosslinked sample analyzed to determine if the gp120 and CD4 molecules remained associated. Briefly, single chain gp120-CD4 from supernatants produced by 293-SC cell line was purified using an immunoaffinity column. The column was constructed by linking anti-gp120 human monoclonal antibody A32 to CNBr-activated sepharose 4B (Amersham-Pharmacia Biotech, Piscataway, NJ). A32 is specific for a highly discontinuous epitope on gp120, and preferentially recognizes envelope bound to CD4. Bound gp120-CD4 was eluted with 0.1M acetic acid pH 2.5, lyophilized, and dialyzed against PBS. Protein concentration was determined by a BCA assay (Bio-Rad, Hercules, CA) using the manufacturer's protocol.

15 A 20 ul aliquot of purified gp120-CD4 was then crosslinked with 1 mM solution of the homo-bifunctional crosslinker, BS3, and electrophoresed along with uncrosslinked gp120-CD4 on a 4-20% polyacrylamide gel. The fractionated proteins were transferred to nitrocellulose, immunoblotted with a mixture of anti-gp120 monoclonal antibodies followed by an alkaline-phosphatase labeled anti-mouse IgG, and visualized with a commercial

20 mixture of BCIP/NBT (KPL). FIG. 3 shows the results of these studies; uncrosslinked gp120-CD4 is in lane 1, and the crosslinked gp120-CD4 is in lane 2.

25 Lane 1 shows that the immunoaffinity column purifies both cleaved and uncleaved single-chain gp120-CD4. Crosslinking, as shown in lane 2, generates two broad bands at 150 kDa and 300 kDa, a pattern suggesting that the single chain gp120-CD4 in solution exists as an associated 150 kDa molecule. The gp120 and CD4 subunits remain associated, even after

30 the cleavage event. The 300 kDa band indicates that a portion of gp120-CD4 is dimeric in

solution and may represent single chain molecules that associate through intermolecular interactions between the envelope and CD4 domains on separate molecules.

The apparent cleavage of the single-chain molecules into gp120 and CD4 moieties under certain conditions (FIG. 2) might be a concern for DNA vaccines, since such processing could potentially occur *in vivo*. However, these studies show that despite cleavage the single-chain molecules remained associated as gp120-CD4 complexes (FIG. 3).

To examine the structural properties of the native FLSC in greater detail, different concentrations (1 $\mu$ M-.03 $\mu$ M) of the same protein preparation examined above were covalently crosslinked in PBS in order to fix any multimeric structures existing in solution. Crosslinked material was then analyzed by immunoblot assay with anti-CD4 antibody.

As shown in FIG. 4, a major protein band (inset; band A) of 172 kD was consistently visible along with two minor bands of higher molecular weight. One of the minor bands (inset; band B) had an apparent size of approximately 302 kD, while the other (inset; band C) failed to migrate far enough into the gel to allow an accurate assessment of size by SDS-PAGE. The appearance and proportions of the different protein bands were not dependent on the FLSC concentration prior to crosslinking. Thus, densitometric analyses indicated that bands A, B and C consistently represented approximately 65%, 25% and 10% of the total protein, respectively.

In comparison to the FLSC, the chromatographic profile of the crosslinked TcSC was more complex. Under non-denaturing conditions TcSC eluted as a broad series of peaks ranging from 166 kD to 353 kD. Such a profile indicated that the shorter TcSC polypeptide forms multiple higher order structures upon expression and/or purification. This behavior indicates that the TcSC exists primarily as variably sized chains of polypeptides joined by interactions between gp120 sequences and CD4 sequences in separate molecules. Since the TcSC was created by deleting 20 C-terminal amino acids from gp120, the distance between the CD4 core structure and the CD4bd of gp120 was shortened which may hinder the ability of the TcSC to achieve an intramolecular gp120-CD4 interaction thereby favoring formation of interchain complexes. Nevertheless, TcSC also exhibited the antigenic and functional features of a gp120-CD4 complex.

It is possible that because of intermolecular interactions involving multiple TcSC molecules, a smaller proportion of the total protein expressed a co-receptor binding site

capable of interacting with surface co-receptors. Alternatively, deletion of the V1/V2 regions in the TcSC may decrease the relative affinity of the BaL envelope for CCR5. Further modification of the TcSC to elongate the linker between the gp120 and CD4 moieties might allow formation of a higher proportion of intrachain complexes. Whether the multimeric nature of the TcSC puts this molecule at a disadvantage to FLSC remains an open question, since studies with other multimeric molecules suggest they are more potent immunogens than their monomeric counterparts (A.L. DeVico *et al.*, *AIDS Rev.*, 1:4-14 (1999); S.A. Jeffs *et al.*, *J Gen Virol.*, 77:1403-1410 (1996); R.A. LaCasse *et al.*, *Science*, 283:357-62 (1999)).

### EXAMPLE III

This Example describes data demonstrating the binding of gp120-CD4 chimeric polypeptide to several different antibodies reactive with gp120 and CD4.

The binding of gp120 to CD4 causes conformational changes in the molecule leading to the exposure of the co-receptor-binding domain. Therefore, antibodies directed against epitopes in this domain should react strongly with properly folded single-chain molecules.

In order to determine exposed epitopes in chimeric molecules, antigenic properties of FLSC and TcSC molecules were compared. Purified FLSC and TcSC were subjected to immunochemical analyses by antigen capture ELISA. In brief, BaLgp120, gp120-rsCD4 complexes or single chain chimeric molecules were captured using a purified polyclonal sheep antibody (International Enzymes, Fallbrook, CA) raised against a peptide derived from the C-terminal 15 amino acids of gp120, D7324 (J. P. Moore *et al.*, *AIDS Res. Hum. Retroviruses*, 4:369-79 (1988)), adsorbed to the matrix. The D7324 was diluted in PBS to 2 ug/ml and adsorbed to 96-well plates (Maxisorb plates, VWR Scientific, St. Louis, MO) by incubating overnight at room temperature. Plates were treated BLOTTO (5% non-fat dried milk in tris-buffered saline) in order to prevent nonspecific binding to the wells. After washing the plates with TBS samples were diluted in BLOTTO and 200 µl aliquots incubated in duplicate D7324-coated wells for 1 hour at room temperature. Bound antigen was detected using a pool of inactivated HIV-1+ sera diluted 1:1000 in BLOTTO followed by goat anti-human IgG labeled with horseradish peroxidase (KPL, Gaithersburg, MD).

Detection was also accomplished using monoclonal antibodies (Mabs A32, 17b and 48d) previously shown to preferentially bind gp120 after engagement of CD4 (M. Thali

*et al.*, *J. Virol.*, 67:3978-86 (1993)), followed by the appropriate-labeled second antibody. Two of the antibodies, 17b and 48d, bind within the co-receptor attachment site that is induced by CD4 binding (N. Sullivan *et al.*, *J. Virol.*, 72:4694-703 (1998); A. Trkola *et al.*, *Nature*, 384:184-6 (1996); L. Wu *et al.*, *Nature*, 384:179-183 (1996)). Antibody C11, which recognizes a conserved epitope in the C1-C5 region of free gp120, was also tested. Antibodies were diluted in BLOTTO and incubated for 1 hour at room temperature. Plates were washed three times with TBS between each incubation step. The amounts of gp120 sequences present in samples were determined based on a standard curve generated with commercial recombinant HIV IIIB gp120 (Bartels, Issaquah, WA). In comparative studies involving BaLgp120-rsCD4 complexes, D7324-coated plates were treated with saturating concentrations of gp120. After washing the wells, an excess concentration of rsCD4 (1 µg/ml) was then added to the wells and incubated for 1 hour to form the complexes. In order to evaluate the TcSC antigen, which lacks the D7324 epitope, an alternate ELISA format using anti-CD4 Mab 45 (Bartels, Issaquah, WA) for capture was developed. The antibody was adsorbed to plastic at 1 µg/ml and wells blocked with BLOTTO. Assays were then carried out as above using the indicated human sera or human monoclonal antibodies.

As shown in FIG. 5A, all of the antibodies reacted strongly with the FLSC. However, the half-maximal binding concentrations of antibodies 17b, 48d, and A32 were consistently higher with FLSC versus gp120 alone, and equivalent to what was observed with soluble, non-covalent BaLgp120-rsCD4 complexes. The higher immunoreactivity of FLSC was specific to the antibodies directed against the CD4-induced epitopes, as there was no significant difference in the half-maximal binding concentrations of antibody C11 with FLSC versus free gp120.

As shown in FIG. 5B, the level of 17b and 48d reactivity with TcSC was equivalent to what was observed with FLSC analyzed in parallel. As expected, antibodies C11 and A32 did not react with TcSC as the bulk of their respective epitopes were deleted from the TcSC construct.

The binding of gp120 and CD4 sequences in the single-chain molecules should also block exposure of epitopes in the CD4 binding site on gp120. To confirm that such binding had occurred, that the CD4 binding site of gp120 was no longer available for binding, FLSC and TcSC were evaluated using the Mab45 capture format and a series of monoclonal

antibodies (IgG1b12, F91, and 205-469) directed against the CD4 binding domain (CD4bd) on gp120.

As shown in FIG. 5C, none of these antibodies reacted with either FLSC or TcSC, although positive reactivity was observed with pooled HIV+ sera tested in parallel. This data indicates an interaction between CD4 sequences and the gp120 CD4 binding domain present within FLSC and TcSC molecules.

In sum, these results demonstrate that gp120-CD4 chimeric polypeptide reactivity was comparable to that observed with complexes made by combining soluble gp120 and CD4 (uncrosslinked), and higher than with gp120 alone. These data indicate that the single-chain gp120-CD4 molecules formed interacting complexes similar to the transition state HIV envelope-CD4 complex. The captured gp120-CD4 was also reactive with anti-CD4 antiserum and anti-myc antibody in other ELISA studies, consistent with the western blot analyses. Taken together, these data indicate that a majority of the single-chain gp120-CD4 molecules represent properly folded gp120-CD4 complexes.

#### **EXAMPLE IV**

This Example describes data demonstrating the binding of gp120-CD4 chimeric molecules, containing a CCR5-specific HIV envelope sequence, to CCR5 expressing cells.

The formation of the gp120-CD4 complex normally exposes the envelope domains that interact with an appropriate co-receptor (M. Thali *et al.*, *J. Virol.*, 67:3978-86 (1993); M.A. Vodicka *et al.*, *Virol.*, 233:193-8 (1997)). Therefore, another measure of properly folded gp120-CD4 complexes and its ability to inhibit virus infection of a cell is the ability to bind to a CCR5 co-receptor.

To evaluate the ability of the single-chain complexes to bind co-receptor, purified single-chain gp120-CD4 molecules were allowed to interact with cells that express either CCR5 or CXCR4. Briefly, supernatants containing gp120-CD4 single-chain were generated by transient transfection of 293 cells with pEF6-SC. Supernatants were then added to an immunoaffinity column of A32 and the purified single-chain eluted with 0.2 M Acetic Acid pH 2.5, and analyzed by D7324-capture ELISA and by immunoblot, as described. Fractions containing single chain were collected, equilibrated to pH 7, and concentrated.

For the binding, the purified single-chain preparation was allowed to interact with L1.2 cells that express CCR5 (L. Wu *et al.*, *Nature*, **384**:179-183 (1996); L. Wu *et al.*, *J. Exp. Med.*, **186**:1373-81 (1997)). L1.2, L1.2/X4, and L1.2/R5 cells, murine B-cells lines that express no co-receptor, CXCR4, or CCR5 were mixed with decreasing concentrations of purified single-chain protein. After incubation at 37° C for 1 hour, the cells were washed. Bound single-chain molecules were detected with 1 ug/ml of Mab C11 (J.E. Robinson *et al.*, *J. Cell. Biochem. Suppl.*, **16E**:71 (1992); M. Thali *et al.*, *J. Virol.*, **67**:3978-86 (1993), an anti-gp 120 Mab, followed by an anti-human IgG that was labeled with a fluorescent molecule, phycoerythrin. C11 recognizes a conformational determinant formed by the C1-C4 regions. The level of bound fluorescence was determined by fluorescence activated cell sorting (FACS) analysis with a FACS Calibur instrument (Beckton Dickinson). The mean fluorescence intensity for each sample was calculated using the Cell Quest 3.1.3 program (Becton Dickinson).

As shown in FIG. 6, both single chain gp120-CD4 complexes (FLSC and TcSC) bound to the CCR5-expressing, but not CXCR4-expressing, L1.2 cells. Maximal binding was observed with FLSC at concentrations (10 ug/ml) equivalent to what was observed with soluble BaLgp120-rsCD4 complexes tested as controls. In comparison, approximately 10-fold higher concentrations of the TcSC were required to approach saturation binding. Thus, gp120-CD4 chimeric polypeptide presents functional co-receptor binding site(s) for CCR5, as expected for a molecule containing a macrophage tropic gp120.

The absence of binding to CXCR4 in these studies was not entirely unexpected in view of the apparent specificity of the HIV envelope polypeptide in the gp120-CD4 chimera for CD4. Thus, by constructing polypeptide chimeras that bind to CXCR4 or other co-receptors, or by modifying a virus coat polypeptide, as described herein, to obtain a chimeric polypeptide that binds to another co-receptor, other virus coat polypeptide-receptor polypeptide chimeras can be obtained that bind to other co-receptors.

To demonstrate that single-chain gp120-CD4 is binding to CCR5 through its co-receptor binding site, competition binding studies with 17b and 48d antibodies, which have been shown to interact with the co-receptor binding site of gp120 and prevent gp120/sCD4 complexes from interacting with co-receptor expressing cells, were performed. For controls, another gp120 antibody, C11, and a gp41 antibody F240, was used. All of these antibodies



are derived from HIV-1 infected patients. Each antibody was used at 10 ug/ml and added together with 3 ug/ml of purified single-chain molecule to L1.2 cells that express either CCR5 or CXCR4. Bound gp120-CD4 was detected with C11, followed by anti-human IgG labeled with PE. The amount of gp120-CD4 was determined by FACS and expressed as a percentage of the total bound in control wells without competing antibody.

As shown in FIG. 7, 17b and 48d strongly inhibited the binding of both single-chain complexes to the cells. In the presence of these antibodies, the binding signal on CCR5-expressing cells was the same as the background binding seen with L1.2/CXCR4, and L1.2 parental cells. Interestingly, 2G12, a potent neutralizing antibody, also reduced the interaction of all complex forms with CCR5. In comparison, anti-gp120 antibodies recognizing epitopes outside the co-receptor binding domain, C11, A32, and an anti-gp41 antibody, F240, all failed to reduce the binding of FLSC or TcSC to the CCR5-expressing L1.2 cells.

These results indicate that the gp120 co-receptor binding site is important for binding to co-receptor. These results also indicate that agents that inhibit binding/interaction between gp120-CD4 and co-receptor can be identified using such an assay. Such agents may have potential value as therapeutics.

In sum, the data demonstrate the successful expression of a soluble, chimeric polypeptide which duplicates the transition state conformation of a virus coat-receptor complex. Given this accomplishment, it is now possible to employ the chimeric polypeptide or polynucleotides encoding the polypeptide for immunization of a subject to produce an immune response to virus or virus having similar coat polypeptide epitopes. The immune response produced can be an antibody (humoral) or CTL response. In addition, given the fact that the chimeric polypeptide binds to an appropriate co-receptor on the surface of living cells, the polypeptide can be administered to subjects acutely exposed to an immunodeficiency virus in order to passively protect cells expressing the co-receptor from virus infection.

#### **EXAMPLE V**

This example describes data demonstrating that a gp120-CD4 chimeric molecule can neutralize infection by HIV strains using the same co-receptor.

The single-chain molecules were further examined for their ability to neutralize R5 and X4 viruses. A total of  $10^4$  U373/CD4/MAGI cells (M.A. Vodicka *et al.*, *Virology*, 233:193-8 (1997)) expressing either CCR5 or CXCR4 were allowed to attach overnight to flat-bottom tissue culture wells. Culture medium was then removed and replaced with 100  $\mu$ l of fresh media containing various concentrations of chimeric protein. An additional 100  $\mu$ l of media containing 50 TCID<sub>50</sub> of virus was then added to the culture. The entire mixture was then incubated at 37°C until syncytia were visible, typically within 3-5 days. Culture wells were then treated with a  $\beta$ -galactosidase chemiluminescent reagent, Galatostar (Tropix, Bedford, MA), according to the manufacturer's protocol. Virus infection was determined as a function of chemiluminescence, quantified using a Victor<sup>2</sup> fluorescence plate reader (EG&G Wallac, Gaithersburg, MD). Background signal was determined in assays carried out in the absence of virus. Signals obtained for the test assays were then corrected by subtracting the background value. Percent infection was calculated by dividing the corrected relative light units for each experimental well by the corrected light units for control wells containing only cells and virus. The 90% inhibitory dose (ID<sub>90</sub>) values were determined from plots of test protein concentration versus percent inhibition of infection. All test conditions were carried out in triplicate.

As shown in FIG. 8, both FLSC and TcSC potently and selectively neutralized the R5 HIV-1BaL isolate, while there was only a slight inhibition (ID<sub>90</sub> > 10 ug/ml) of 2044 isolate. In comparison, uncomplexed BaLgp120 inhibited entry of both HIV-1BaL and X4 (HIV-12044) viruses as expected due to its direct interactions with CD4.

Thus, the data demonstrate that a virus coat polypeptide-receptor chimeric molecule can bind to a cellular co-receptor thereby blocking binding or infection of the cells by virus that utilize the co-receptor for binding or infection.

## **EXAMPLE VI**

This Example describes the construction and expression of a modified gp120-CD4 chimeric polypeptide having an immunoglobulin polypeptide sequence, gp120-CD4-IgG1. This exemplary heterologous domain adds functionality to the gp120-CD4 chimeric polypeptide, including adhesin and immunopotentiating functions, prolonging stability, increasing circulating half-life and ability to cross the placental barrier. This example also

shows that the gp120-CD4-IgG1 chimera binds to co-receptor expressed on the surface of intact cells and neutralizes HIV virus.

Gp120, a subunit of the envelope protein of HIV-1, binds to CD4 and undergoes a conformational change that permits the complex to interact with a co-receptor, such as CCR5. This interaction permits the infection of HIV-1 into target CD4+ cells. Antibodies or other agents that interfere with the interaction of HIV-1 with the co- receptor can prevent infection.

To identify such agents, single-chain gp120-CD4 was modified by fusion to the constant regions that form the IgG1 heavy chain, C1, C2, and C3 (FIG. 9). Gp120-CD4-IgG1 can be used to identify agents that block, inhibit, or disrupt HIV-1 interaction with the co-receptor, thereby identifying agents that inhibit HIV infection. The gp120-CD4-IgG1 also could be used as a passive immunotherapeutic to prevent HIV infection after an accute exposure, such as a needlestick injury.

Two hundred ninety-three cells were transiently transfected with the plasmid containing gp120-CD4-IgG1, and the expressed protein was characterized by immunoblotting of the culture supernatants. Briefly, collected supernatant samples were electrophoresed onto a 4-20% gradient PAGE gel. Fractionated proteins were transferred to nitrocellulose and detected with a mixture of anti-gp120 monoclonal antibodies. As shown in FIG. 10, the transiently transfected cells expressed gp120-CD4-IgG1 (lane 1). Supernatant from cells expressing purified gp120 derived from HIV-1<sup>BaL</sup> (lane 2) was electrophoresed for relative size comparison. The gp120-CD4-IgG1 polynucleotide encodes a protein having the predicted size for a gp120-CD4-IgG1 heavy-chain chimera. Like the original gp120-CD4, a portion of gp120-CD4-IgG1 is cleaved producing a 120 kDa protein fragment that is most likely gp120 ("Cleaved gp120"). The size of this fragment suggests that gp120-CD4-IgG1 is being cleaved within the spacer.

To assure that the gp120-CD4-IgG1 is folded into a conformation permissive for binding co-receptor, dilutions of the supernatant were added to L1.2 cells that express either CCR5 or CXCR4 co-receptors. Bound gp120-CD4-IgG1 was detected with anti-human IgG that was labeled with Europium, a fluorescent reagent. The amount of fluorescence is directly related to the amount of bound material.

As shown in FIG. 11, gp120-CD4-IgG1 binds specifically to L1.2 cells that express CCR5. Again, little binding to CXCR4 was detected using this assay, which is consistent with the results for gp120-CD4. These studies indicate that heterologous domains conferring additional or enhanced functionality can be added to chimeric molecules without affecting their ability to form a complex that binds to cell co-receptor.

To confirm that binding of chimeric gp120-CD4-IgG1 heavy chain to CCR5 expressing cells was mediated by co-receptor binding site of gp120, binding was studied in the presence of blocking antibody 17b. Briefly, for the Mab/FLSC-IgG1 competition studies, sodium butyrate activated L1.2 cells expressing co-receptor were added to V-bottom plates at  $10^5$ /well. 10 ug/ml FLSC-IgG1 and 1 ug/ml Mabs were added to the cells. Cells and protein were incubated together for 1 hour at 37°C. Cells were pelleted and washed with TBS three times. Bound material was detected with phytoerytherin-labeled anti-human IgG at 5 ug/ml for 1 hour at 4°C. The cells were washed three times with TBS then analyzed by fluorescence-activated cell sorting (FACS).

As shown in FIG. 12, 17b, an antibody that recognizes the CCR5-binding domain on gp120, blocks FLSC-IgG interaction with L1.2/R5 cells while control antibody, F240, does not. These data demonstrate that the FLSC-IgG interacts with the R5 co-receptor via the R5-binding domain on gp120.

To confirm that chimeric gp120-CD4-IgG1 heavy chain could block virus entry into cells, neutralization assays were then performed. In brief, U373/CD4/MAGI cells that express either CCR5 or CXCR4 were allowed to attach to flat-bottom tissue culture trays overnight at  $10^4$  cells/well. The medium was removed and varying concentrations of mAbs and immunoadhesins were then added to cells in 100 µl of media. Virus (50 TCID<sub>50</sub>/well of in 100 ul of media) was then added and the mixture incubated at 37°C until syncytia were visible, typically 3-5 days. Plates were read using a β-galactosidase chemiluminescent reagent, Galatostar, according to the manufacturer's protocol and the chemiluminescence produced was quantified using a Victor<sup>2</sup> as previously described. Percent virus growth was calculated by using the relative light units for (experimental well)--background wells with no virus)/(wells with virus but no protein)--(background wells) (Table 2). ID<sub>50</sub> and ID<sub>90</sub> were determined graphically.

**TABLE 2**  
**Neutralization of X4, R5, and X4/R5**  
**HIV by FLSC-IgG1**

<b>U373/CD4/CCR5</b>					
	<b>FLSC-IgG1</b>	<b>2G12</b>	<b>2F5</b>	<b>1gG1b12</b>	<b>Control 1gG</b>
<b>ID90 (µg/mL)</b>					
<b>BaL</b>	3.1	>10	>10	1.57	>10
<b>ADA</b>	4.58	>10	>10	>10	>10
<b>89.6</b>	3.56	8.07	>10	3.39	>10

<b>U373/CD4/CXCR4</b>					
	<b>SC1g</b>	<b>2G12</b>	<b>2F5</b>	<b>1gG1b12</b>	<b>Control 1gG</b>
<b>ID90 (µg/mL)</b>					
<b>2044</b>	>10	>10	>10	1.57	>10
<b>2005</b>	>10	>10	>10	>10	>10
<b>89.6</b>	>10	>10	>10	5.34	>10

The data in Table 2 indicate that FLSC-IgG blocks viruses that use R5 for cell entry. FLSC-IgG neutralizes virus as effective as 2G12, 2F5, and IgG1b12, antibodies that are currently being evaluated in passive immunotherapy trials. These data therefore further affirm the usefulness of gp120-CD4 chimeras to inhibit HIV infection in particular, and the applicability of virus coat protein-receptor chimeras as inhibitors of other viruses that utilize co-receptor for binding or cell penetration in general.

### **EXAMPLE VII**

This Example describes data demonstrating that mutation of the furin cleavage site improves the stability of the FLSC complex.

The position of the cleavage site that separates the FLSC fragments is probably located within the C terminal gp120 sequences present only in FLSC, since the shorter TcSC did not exhibit degradation. Notably, these sequences encompass the gp120/gp41 junction normally cleaved by the furin protease (M. Girard *et al.*, *C R Acad Sci III.*, 322:959-66 (1999)). Cleavage of the FLSC at the natural furin site would be consistent with the behavior of the FLSC fragments, as it would have minimal impact on the structures of the gp120 and CD4 moieties and their capacity to interact.

In order to determine if this putative furin site accounts for cleavage, BaLgp120, BaLgp120 complexed with an sCD4 molecule consisting of the first two domains (V1V2) of CD4, FLSC, and FLSC R/T were captured onto plastic via an antibody specific for the C-terminus of gp120 (antibody binding was unaffected by the R/T mutation). Four domain V1-  
5 V4 sCD4 were titrated onto the captured complexes starting at 30 ug/ml. Four domain sCD4 has a higher affinity for gp120 than the two domain V1V2 and, therefore, would compete off the smaller unit from complexes. Bound four domain CD4 was detected with antibody OKT4, which only binds the four domain CD4. The results in FIG. 13 show that mutation of  
10 the furin cleavage site prevents the V1V2 found on the FLSC R/T from dissociating as readily as the cleaved FLSC, thus improving its stability of the FLSC R/T complex.

It is to be understood that, while the invention has been described in conjunction with the detailed description thereof, the foregoing description is intended to illustrate and not limit the scope of the invention, which is defined by the scope of the appended claims. Other aspects, advantages, and modifications are within the scope of the following claims.